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Coastal and Hydraulics Laboratory

US Army Corps
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Development Center

Brownsville Ship Channel Hydrodynamic Modeling

Jennifer N. Tate and Cassandra G. Ross

January 2012

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Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
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Final report

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Prepared for US Army Corps of Engineers
Galveston District

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Abstract

The US Army Engineer District, Galveston, requested a numerical model of hydrodynamic changes that would result from each of several possible enlargements of the Brownsville Ship Channel in Brownsville, Texas. These plans include possible deepening and widening of the ship channel from its connection to the Gulf of Mexico to the turning basin approximately 18 miles inland. The model was validated to flow, wind, and tide conditions from June 1997. Model-specific parameters for bed roughness were set and used for the plan simulations. Velocity, discharge, and water surface analyses were performed at several locations along the ship channel to determine the impacts of the proposed changes.

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Preface

The study documented in this report was conducted for the US Army Engineer District, Galveston (CESWG) under Military Interdepartmental Purchase Request MIPRW45VAK72110304, "BIH Feasibility Study–Hydro Modeling," dated 31 July 2007. The report presents the findings of an investigation of the hydrodynamic changes that would occur under various plans to modify the width and depth of the Brownsville Ship Channel.

The investigation was performed by the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), Vicksburg, MS. The work was performed under the general direction of Dr. William D. Martin, Director; and Mr. Jose Sanchez, Deputy Director, ERDC-CHL. Direct supervision was provided by Mr. Bruce A. Ebersole, Chief, Flood and Storm Protection Division (CEERD-HF), and Dr. Robert McAdory, Chief, Estuarine Engineering Branch (CEERD-HF-E).

This investigation was conducted from May 2007 through October 2009 at the US Army Engineer Research and Development Center (ERDC) by Ms. Jennifer N. Tate, Ms. Cassandra G. Ross, and Mr. Tate O. McAlpin of the Coastal and Hydraulics Laboratory (CHL).

At the time this report was published, Dr. Jeffery P. Holland was the Director of ERDC, and COL Kevin J. Wilson was the Commander and Executive Director.

1 Introduction

1.1 Background and objective

The Brownsville Navigation District is proposing improvements to the Brownsville Ship Channel, to include potential deepening and widening. In order to assess the impacts of these changes on both navigation and the ecosystem, it is necessary to perform a numerical analysis of the proposed changes to the system. At the request of the US Army Corps of Engineers (USACE) District, Galveston (SWG), the Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) performed a numerical model study of proposed changes to the channel, which is located at the southern tip of Texas. Figure 1 shows the project location.

ERDC has conducted several studies in the south Texas vicinity, including a recent navigation study at Port Isabel. The model mesh used for the Port Isabel study included all of the Brownville Ship Channel, and was performed using the TABS-MDS numerical model.[1] Previously this model was used to determine the effects of wind-wave resuspension and circulation of sediment in Laguna Madre.[2]

The navigation impacts are assessed by performing model simulations of the currents in the Brownsville Ship Channel for both existing conditions and for several proposed alternatives. The currents are then provided to the ERDC Ship/Tow Simulator[3], where they can be assessed for impacts to navigation.

The hydrodynamic impacts are analyzed using the Adaptive Hydraulics (AdH) numerical model code (see Appendix). Sufficient field data are already available for the validation of the hydrodynamic model. It is assumed that a two-dimensional (2D) depth-averaged implementation of the model is adequate for the intended analysis. This assumption is supported

[1] For description, see http://chl.erdc.usace.army.mil/tabs.

[2] Teeter, Allen M., Gary L. Brown, Michael P. Alexander, Christopher J. Callegan, M. Soraya Sarruff, and Darla C. McVan, *Wind-Wave Resuspension and Circulation of Sediment and Dredged Material in Laguna Madre, Texa*s, review draft (Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, January 2003).

[3] For description, see http://www.erdc.usace.army.mil/pls/erdcpub/WWW_WELCOME.NAVIGATION_PAGE?tmp_next_page=50966.

by the very small inflows of fresh water and, thus, a lack of significant stratification in the channel.

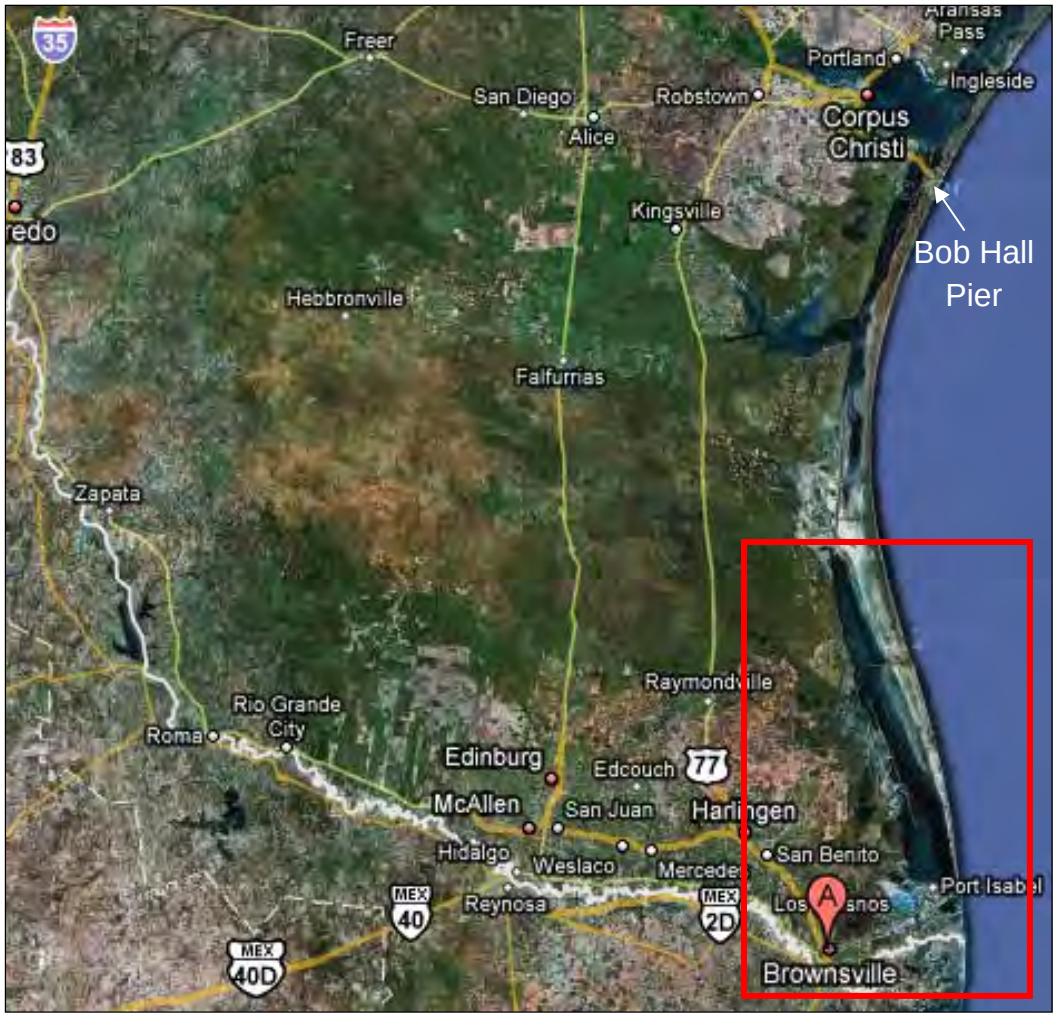

Figure 1. Project location.

1.2 Technical approach

In order to perform the requested simulations, the following approach was implemented:

1. Convert the TABS-MDS mesh to the AdH structure and add mesh resolution.
2. Validate the model for hydrodynamics.
3. Perform the simulations.

Much of the initial mesh and model parameters were taken from previous ERDC-CHL work performed from 1997 to 2002.[4] Resolution was added to the model domain to better resolve the shallow-water habitats, including South Bay, Bahia Grande, and South Laguna Madre. These habitats are discussed further Chapter 2.

The model was re-validated for hydrodynamics after changes were made to the modeling tool and incorporation of the additional areas noted above. The current work includes a model validation to 1997 conditions. The boundary conditions include tidal water surface elevation at the ocean boundaries for Port Mansfield and Brazos Santiago as well as a river inflow at the Arroyo Colorado. Winds affect the currents generated in the model, and wind input to the model was based on data from stations within the model domain.

Simulations are performed for several widening and deepening scenarios, and the results are passed to the ERDC Ship/Tow Simulator for determination of the effects the changes have on navigation. Twelve plan conditions were simulated, as directed by SWG:

- Initial-Plan 1 – widen the channel by 200 ft[5] (450 ft total width) using the design depth of 42 ft (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- Initial-Plan 2 – widen the channel by 200 ft (450 ft total width) and deepen to 45 ft (with 3 ft of overdredge and advanced maintenance for a 48 ft total depth)
- Initial-Plan 3 – widen the channel by 200 ft (450 ft total width) and deepen to 48 ft (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- S26-Plan1 – widen the channel by 200 ft (450 ft total width) from mouth to Station 26 and maintain the design depth of 42 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- S26-Plan2 – widen the channel by 200 ft (450 ft total width) and deepen to design depth of 45 ft from mouth to Station 26 and maintain the design depth of 42 ft the remaining extent of the channel (with 3 ft of overdredge and advanced maintenance for 48 and 45 ft total depths, respectively)

[4] Teeter et al., *Wind-Wave Resuspension*, January 2003.

[5] 1 ft = 0.3048 m.

- S26-Plan3 – widen the channel by 200 ft (450 ft total width) and deepen to design depth of 48 ft from mouth to Station 26 and maintain the design depth of 42 ft the remaining extent of the channel (with 3 ft of overdredge and advanced maintenance for 51 and 45 ft total depths, respectively)
- Deepen Only-Plan 1 – maintain the design depth of 42 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- Deepen Only-Plan 2 – deepen to 45 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 48 ft total depth)
- Deepen Only-Plan 3 – deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- Plan-300 ft – widen the channel by 50 ft (300 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- Plan-350 ft – widen the channel by 100 ft (350 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- Plan-400 ft – widen the channel by 150 ft (400 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)

Further details of these plans are provided in Chapter 4.

2 Model Domain and Boundary Conditions

The Brownsville Ship Channel is located in extreme south Texas near the Mexican border. The ship channel is connected to the Gulf of Mexico and extends approximately 18 miles[6] inland to Brownsville. The ship channel also connects to the Laguna Madre, just inland of the Gulf. The ship channel is fairly straight, although there are some direction changes as the channel extends to the turning basin. The project location is given in Figure 1 (see p 2). Much of the field data used for boundary conditions and model validation were obtained from the Texas Coastal Ocean Observation Network (TCOON, http://lighthouse.tamucc.edu/TCOON/HomePage).

2.1 Mesh characteristics

The original mesh domain was obtained from previous work performed in the Laguna Madre and Port Isabel areas.[7] Those simulations were performed using the TABS-MDS modeling tool. However, the current work is being modeled using AdH, so mesh changes are necessary. The initial model domain is given in Figure 2. The same model domain is used for the AdH mesh with the inclusion of the Bahia Grande area to the north of the Brownsville Ship Channel. Since the Bahia Grande was not connected to the ship channel until summer 2006, its inclusion in the model calculations is dependent on the time period being simulated. To convert the TABS-MDS mesh to an AdH mesh, the internal element structure changes to include only linear, triangular elements. Figures 3 and 4 show the AdH model domain as well as the additional Bahia Grande area included for this effort. A 2007 FEMA survey was intended to provide the bathymetry for the Bahia Grande area, but the detailed bathymetry did not include this entire area and therefore much of the bathymetry had to be estimated. With these changes, the AdH mesh contains 37,809 linear, triangular elements and 19,887 nodes. The vertical model datum is mean lower low water (MLLW) and the coordinate system is State Plane Texas South (NAD27).[8]

[6] 1 mile = 1,609.347 meters.

[7] Teeter et al., *Wind-Wave Resuspension*, January 2003.

[8] North American Datum of 1927 (NAD27).

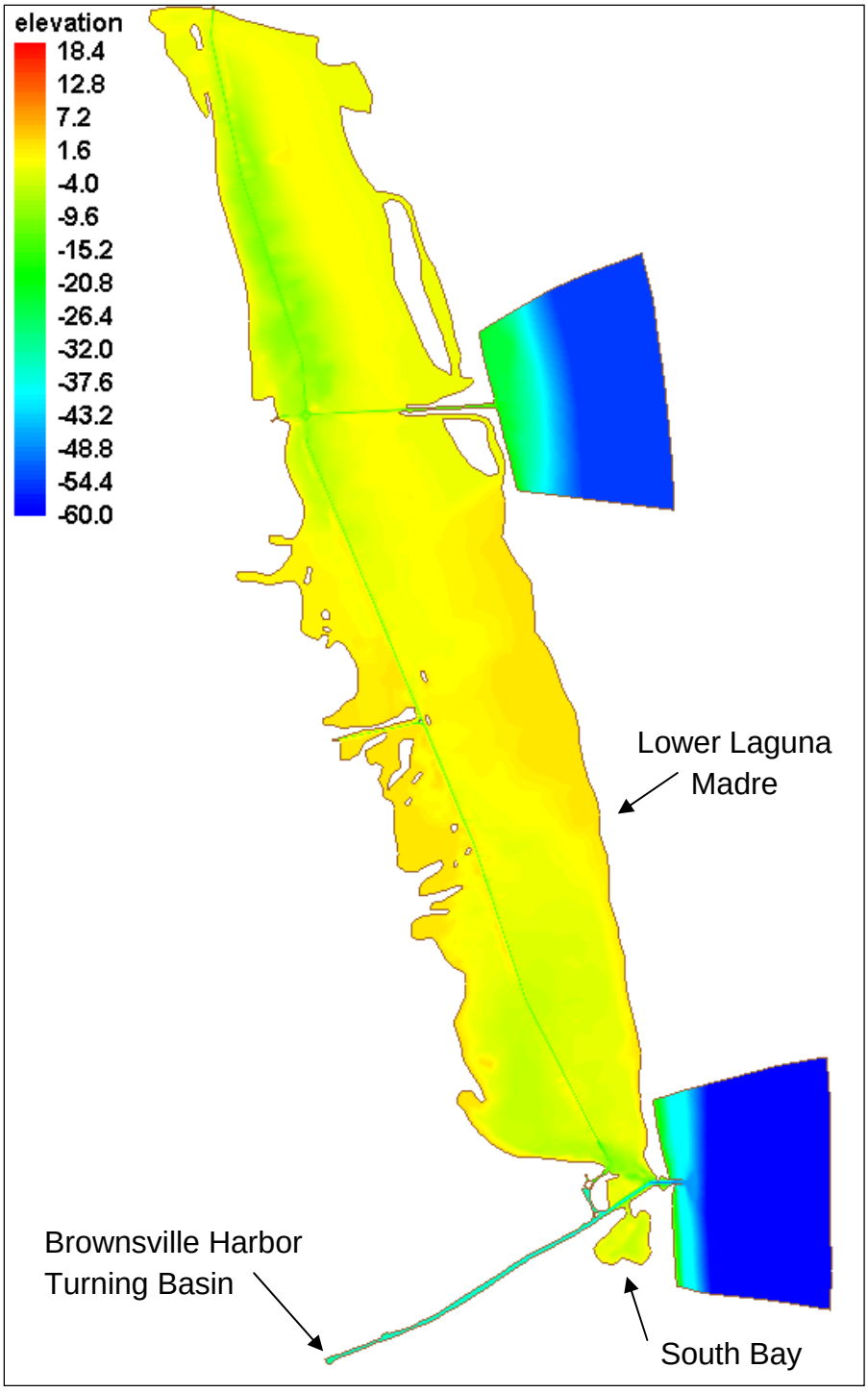

Figure 2. Initial model domain from TABS-MDS (elevation, ft).

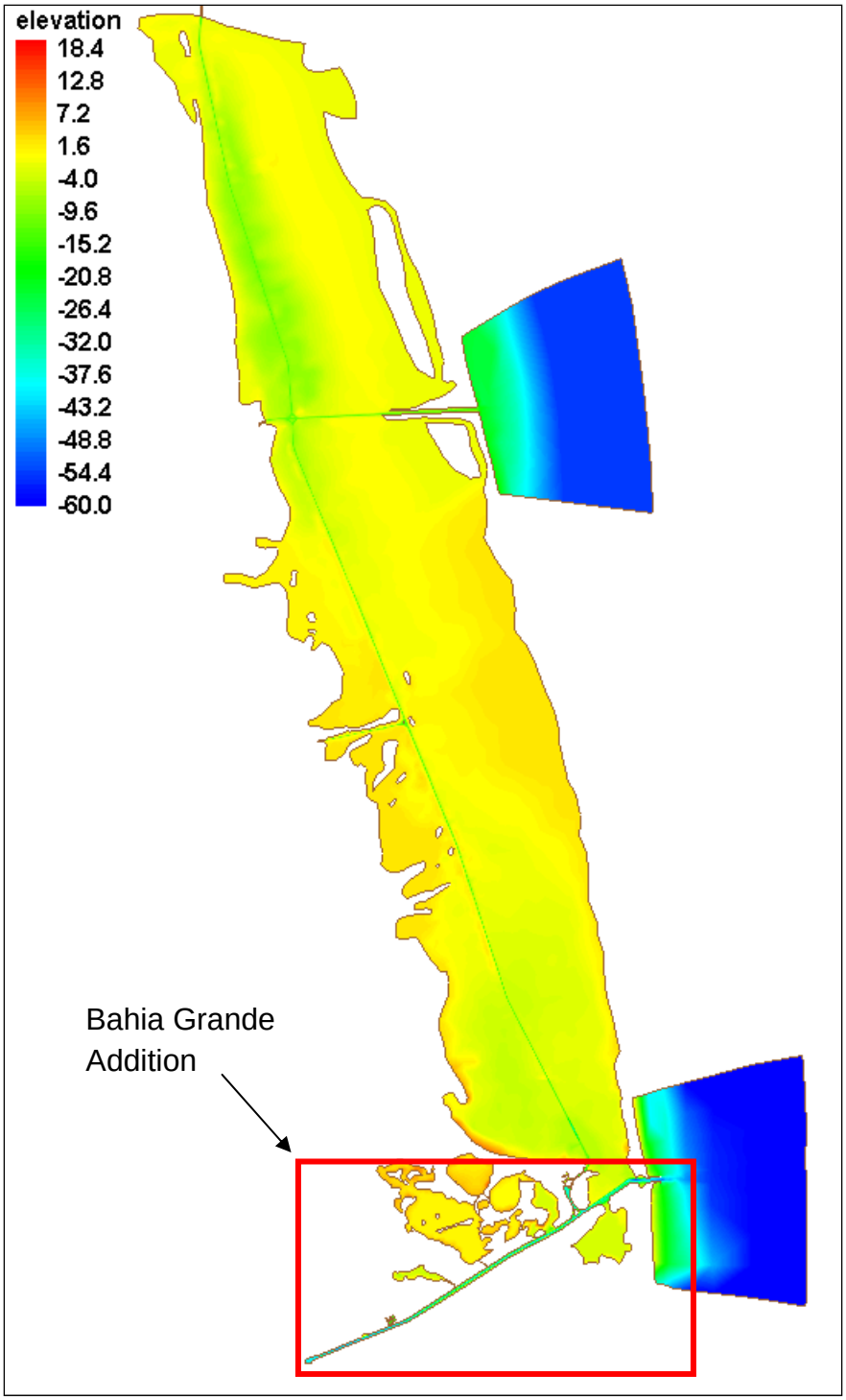

Figure 3. Numerical model domain (elevation, ft).

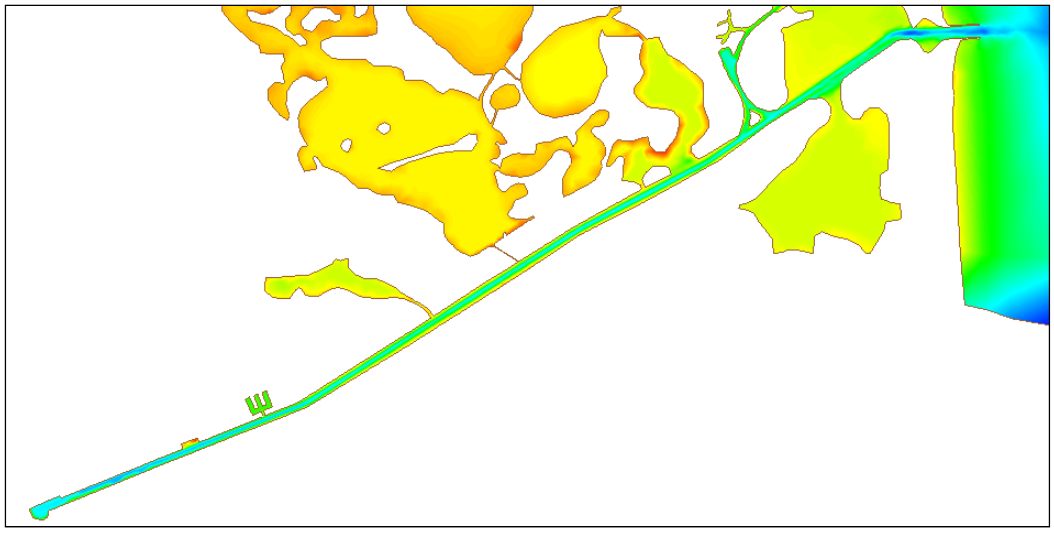

Figure 4. Brownsville Ship Channel model domain (see elevation scale in Figure 2).

The mesh resolution is set in the Brownsville Ship Channel study area such that there are 5 to 7 elements defining the channel bottom. This is typical for finite element meshes and adequate for passing data to the ship simulator. An additional 2 to 3 elements are included to define the channel side slope such that a 1:3 ratio is used for vertical-to-horizontal change. This side slope is maintained for all channel widths modeled. The mesh boundary is maintained for all plans, but the elevations and element alignment are adjusted depending on the channel width required for a given plan. Figure 5 shows the mesh resolution for the Brownsville Ship Channel as it exits the Laguna Madre area and enters into its landlocked portion.

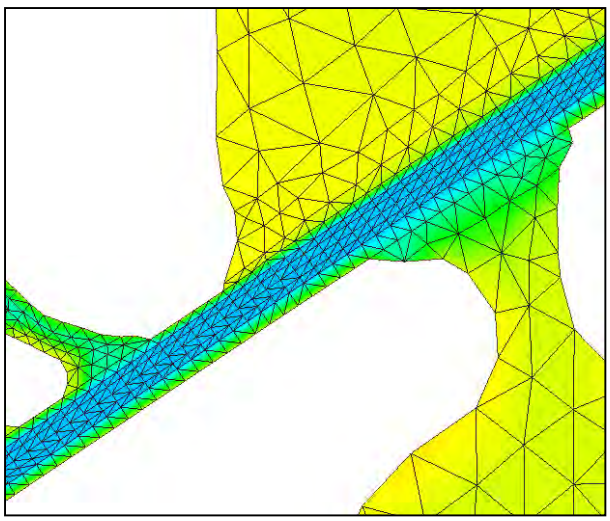

Figure 5. Mesh resolution for the Brownsville Ship Channel study area.

2.2 1997 boundary conditions

The model validation is performed using field data from June 1997. The model is driven by tidal elevations applied at the ocean boundaries out from the Gulf entrances at Brazos Santiago and Port Mansfield, located as shown in Figure 6. The tide data applied are obtained from the National Oceanic and Atmospheric Administration (NOAA) station at Bob Hall Pier (see Figure 1 on p 2), as done in the previous study.[9] This gage was chosen for the tidal boundary condition due to its location on the Gulf of Mexico side of the barrier islands. It is approximately 100 miles from the Brazos Santiago tidal boundary condition location, but the tidal signal is similar at these locations and the model validation is intended to verify that the tidal elevation is reproduced in the study area correctly. Figure 7 shows this tidal signal, as used for both entrances. A river inflow condition is also applied at the Arroyo Colorado. This flow volume was set according to the previous work using the 1997 data as well, and is a constant 500 ft^3/s.[10]

In addition to the tide and inflow conditions that drive the model simulations, wind stresses are applied to the model based on the wind speed and direction at various locations. Three wind stations are used for these simulations, as shown in Figure 8: Coast Guard Station TCOON #51, Station 14; Port Mansfield TCOON #17, Station 17; and Rincon de San Jose TCOON #3, Station 18. These data were all obtained at 10 meters above the surface and filtered to remove signals less than 3 hours so that noise in the data does not affect the model response. The wind speeds for June 1997 at each of these stations are given in Figure 9, and the wind directions in the standard meteorological format are given in Figure 10. No wind was applied in the Gulf of Mexico locations since the tide boundary includes wind effects and the water surface elevation comparisons are good inside the model domain.

[9] Teeter et al., *Wind-Wave Resuspension*, January 2003.

[10] 1 ft^3/s = 0.02831685 m^3/s.

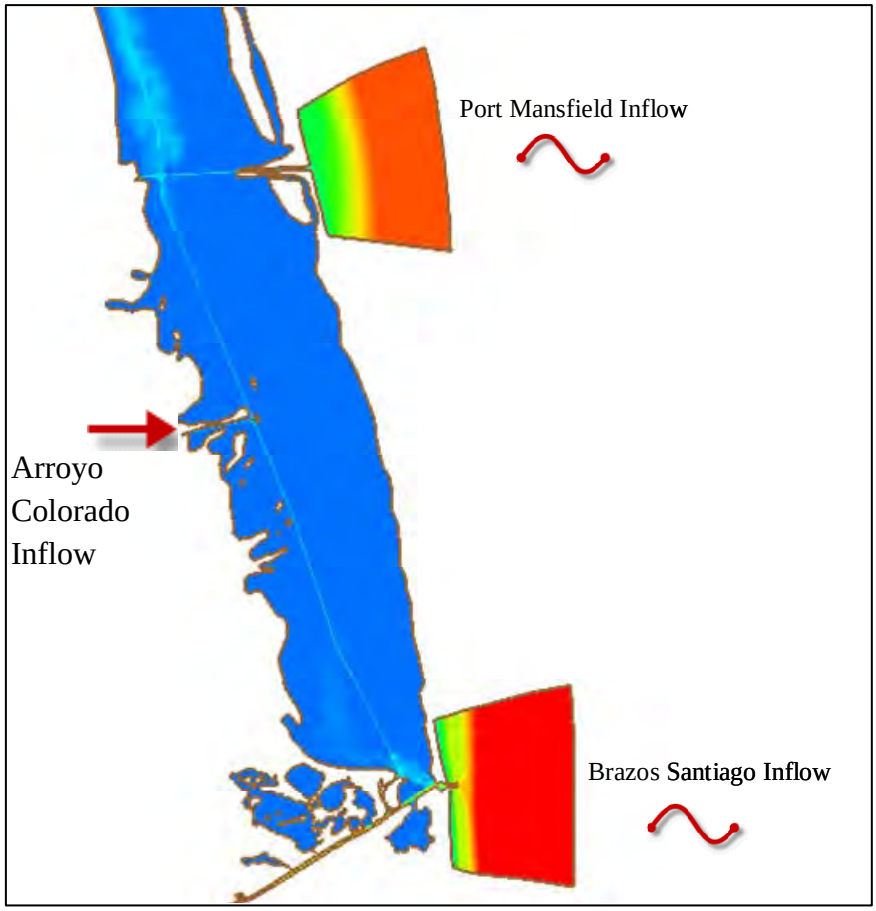

Figure 6. Tide and inflow boundary conditions.

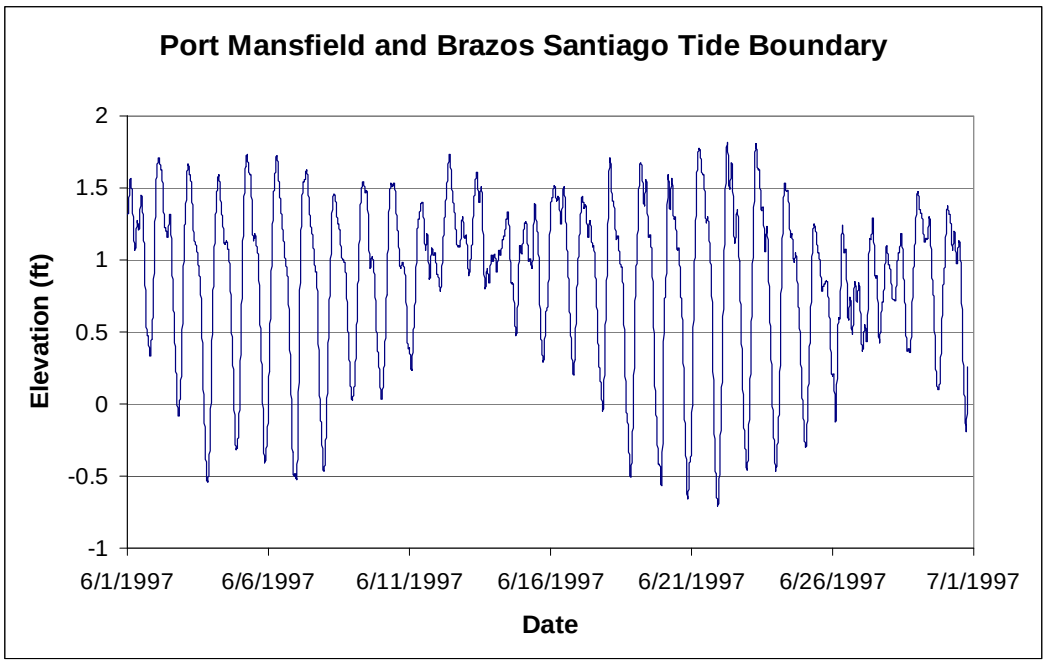

Figure 7. Tidal elevation boundary condition (MLLW).

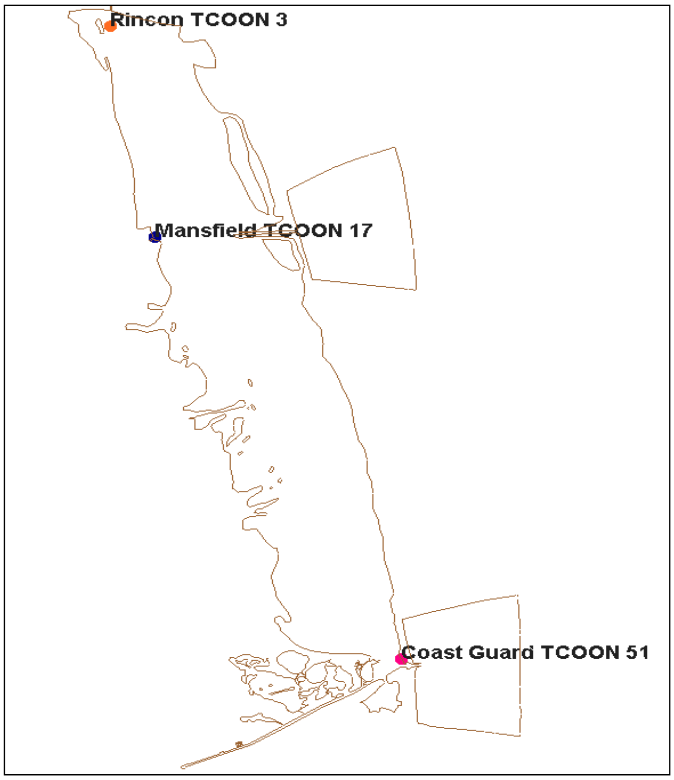

Figure 8. Location of wind stations.

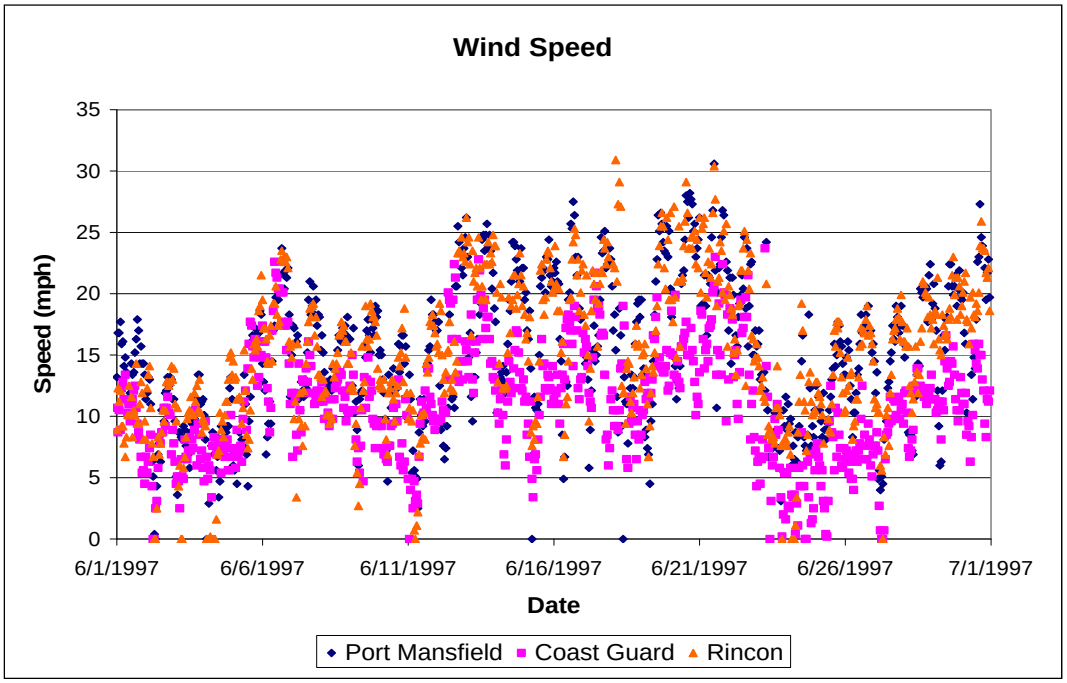

Figure 9. 1997 wind speeds.

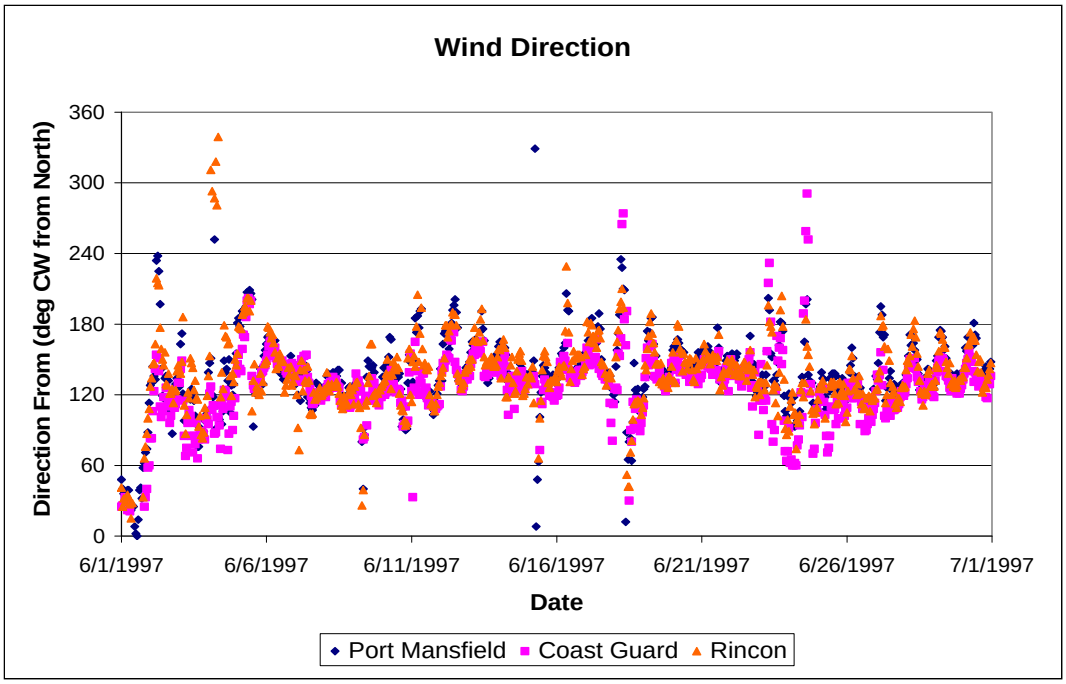

Figure 10. 1997 wind direction (degrees from, clockwise from North).

3 Model Validation Results

With the boundary conditions defined as given in Chapter 2, the model was run using AdH, a finite element code that is capable of simulating three-dimensional (3D) Navier Stokes equations, 2D and 3D shallow-water equations, and groundwater equations. It can be used in a serial or multiprocessor mode on personal computers, UNIX, Silicon Graphics, and CRAY operating systems. The uniqueness of AdH is its ability to dynamically refine the domain mesh in areas where more resolution is needed at certain times due to changes in the flow conditions. AdH can simulate the transport of conservative constituents such as dye clouds, and hydrodynamically coupled density flows such as salinity, as well as sediment transport that is coupled to bed and hydrodynamic changes. The ability of AdH to allow the domain to wet and dry within the shallow areas as the tide changes is suitable for the shallow Laguna Madre environment. This tool has been developed by ERDC-CHL as part of the System Wide Water Resources Program (SWWRP). It has been used to model sediment transport in sections of the Mississippi River and Louisiana, tidal conditions in southern California, and vessel traffic in the Houston Ship Channel.

For this study, the 2D shallow-water module of AdH is used for all simulations. This tool solves for depth and depth-averaged velocity throughout the model domain. In this application, density effects due to salinity or other factors are neglected, so their effects on the flow are not included in these simulations and results. This is an acceptable approach since this area is well mixed, with few vertical salinity gradients and very small fresh water inflows in the channel. More details of the 2D shallow-water module of AdH, its computational philosophy, and equations can be found at https://adh.usace.army.mil and in the Appendix.

3.1 1997 validation

The 1997 validation period included model/field measurement comparisons to water surface elevation, discharge, and velocity values at several locations within the model domain. The field data used for validation were obtained from several locations from the Texas Water Development Board (TWDB) and TCOON system.

ADCP discharge data were taken during an intensive data collection in the Lower Laguna Madre in 1997 by the TWDB in conjunction with the Conrad Blutcher Institute and the United States Geological Survey (USGS). These data are compared at Brazos Santiago Pass, South Bay, Port Isabel Channel, Queen Isabel Causeway, and Port Mansfield. The locations of the discharge comparisons are shown in Figure 11. The model comparisons are given in Figures 12 – 16.

These discharge comparisons show good agreement of the model to the limited data available. Several of the stations have less than a tidal cycle of discharge data, which can miss the peaks of the discharge. At Brazos Santiago (Figure 12) the model-computed results are good for timing and predicting the ebb flow (toward the gulf). However, the model misses the highest flood-directed flows. At South Bay (Figure 13) the comparison is also good. The model reproduces a semi-diurnal tendency for this area, which is indicated in the field data. The model also gives a better prediction for the highs and lows of the flow signal than at the previous location. At Queen Isabel and Port Isabel there is less than a tidal cycle of discharge field data. These data do, however, indicate the peak flood and ebb discharges, which are matched well at Queen Isabel (Figure 14). The model misses the maximum flows at Port Isabel (Figure 15) by almost half. This is likely due to the complex geometry of this area and uncertain bathymetry data. The Port Mansfield location (Figure 16) is much farther away from the study area than the other gages. Its comparison to the field is very good on the timing of flood and ebb events and reasonable on the magnitudes.

Water surface elevation data were obtained during the same data collection effort at South Bay, Port Isabel (TCOON #81), Coast Guard Station (TCOON #51), Arroyo Colorado (TCOON #47), Port Mansfield (TCOON #17), and Rincon de San Jose (TCOON #3). Figure 17 shows the location of each of these comparison points. Figures 18 – 23 give the model/field comparison for June 1997. All water surface elevation data are presented in MLLW.

The water surface elevation computations from the model, when compared to the field data, better represent the southern portion of the system than the area to the north. The northern area consists of marshlands and very low depths. Much of this area is not even modeled due to its limited wetting, making this area of the model domain much more difficult to reproduce. Since the area of study is the ship channel to the far south, the

comparisons to the north are not as significant as those at locations in the southern area of the model domain. However, the model does replicate the elevation patterns in the northern modeled area and is sufficient for base/plan model comparisons. At the South Bay Pass, Coast Guard, and Port Isabel locations the water surface elevation comparisons are good. The model often overpredicts the low elevation and slightly underpredicts the high elevations, giving a slightly larger tidal range than seen in the field. Moving north, the model underpredicts the tidal range by a significant amount at Arroyo Colorado. This is likely due to the river inflow at this location and unaccounted areas of wetting and drying. The model includes an inflow here, but it is set at a constant since a detailed representation of this flow is unknown. At Port Mansfield, the modeled elevations are low for the first half of the month, and then better comparisons are made in the latter half of the month. The small field variations are not picked up by the model, but the overall trend of the water surface is replicated. The Rincon location, at the far north, shows a good comparison to water level magnitude and trend, although the range is lower in the model than in the field. There are unaccounted-for areas of wetting and drying near the Rincon and Port Mansfield areas, and these contribute to inaccuracies at these two modeled locations.

The raw data for this data collection can be obtained through the TWDB at http://midgewater.twdb.state.tx.us/bays_estuaries/studies/llm97main.html.

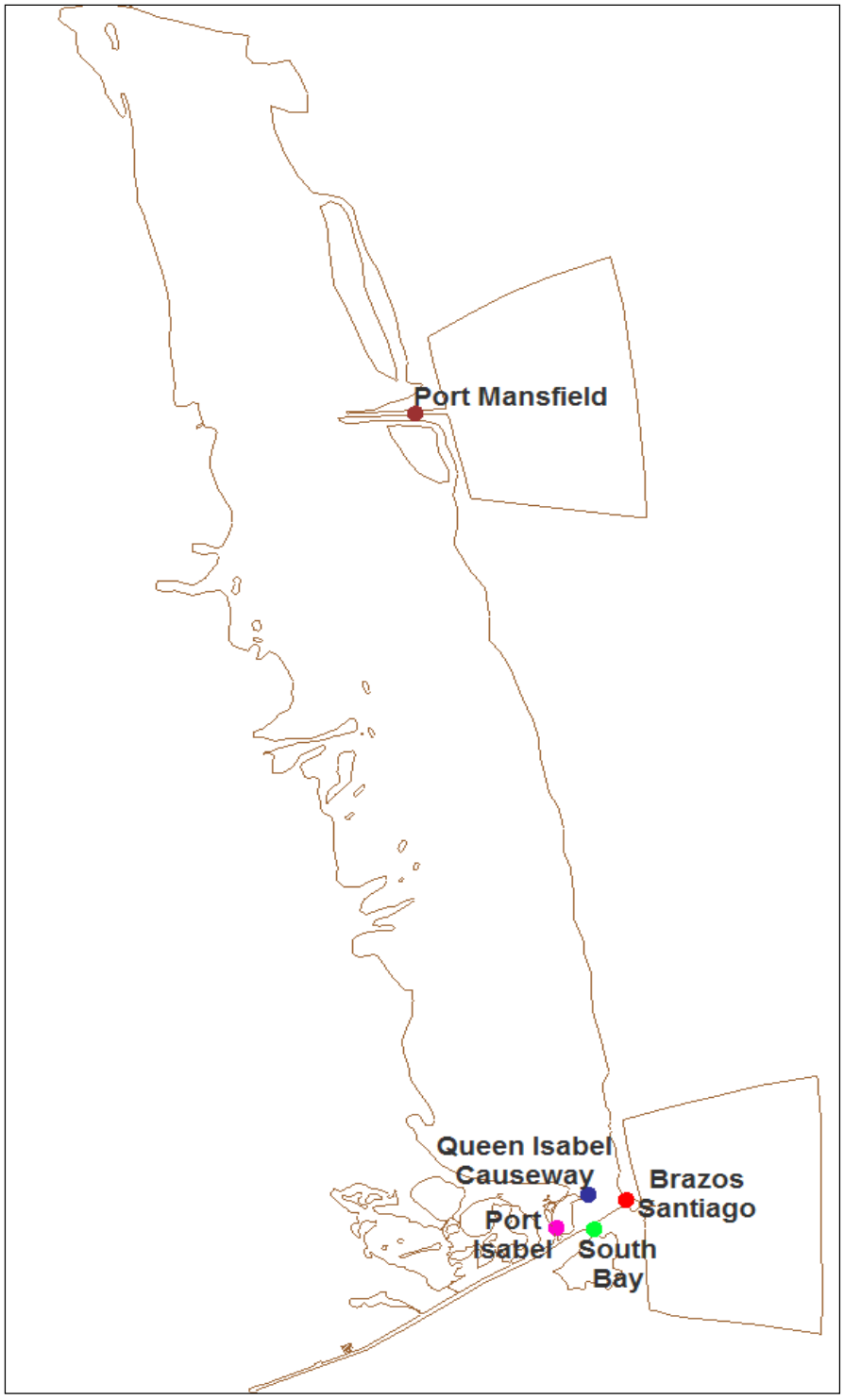

Figure 11. Discharge comparison locations.

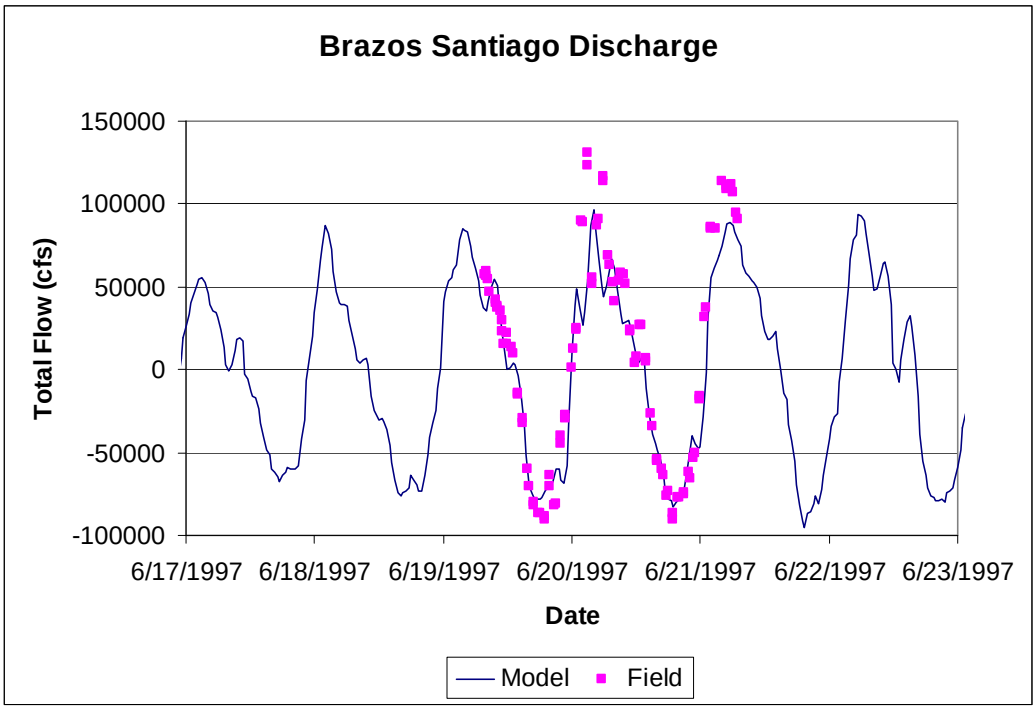

Figure 12. Discharge comparison at Brazos Santiago for June 1997.

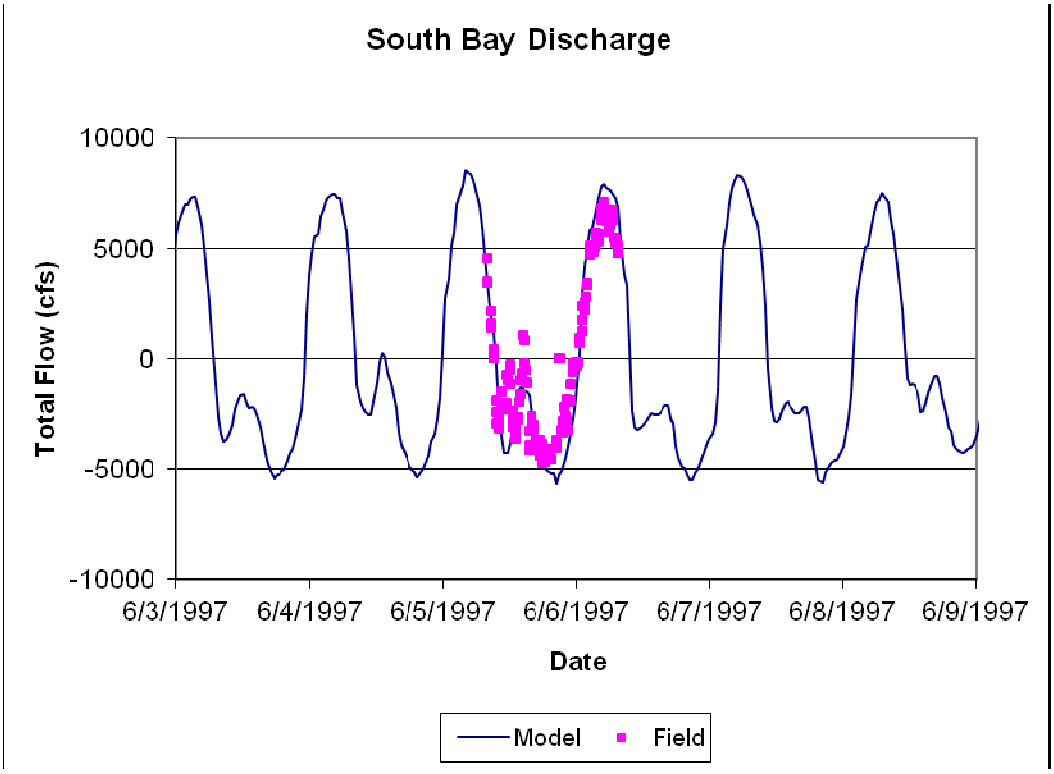

Figure 13. Discharge comparison at South Bay for June 1997.

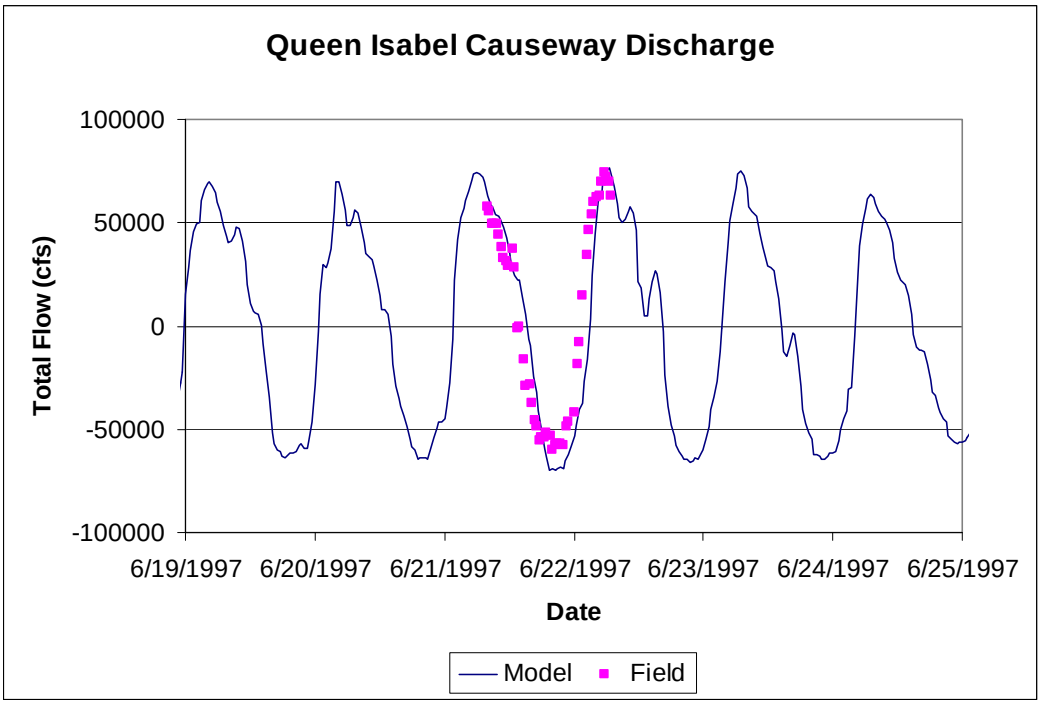

Figure 14. Discharge comparison at Queen Isabel Causeway for June 1997.

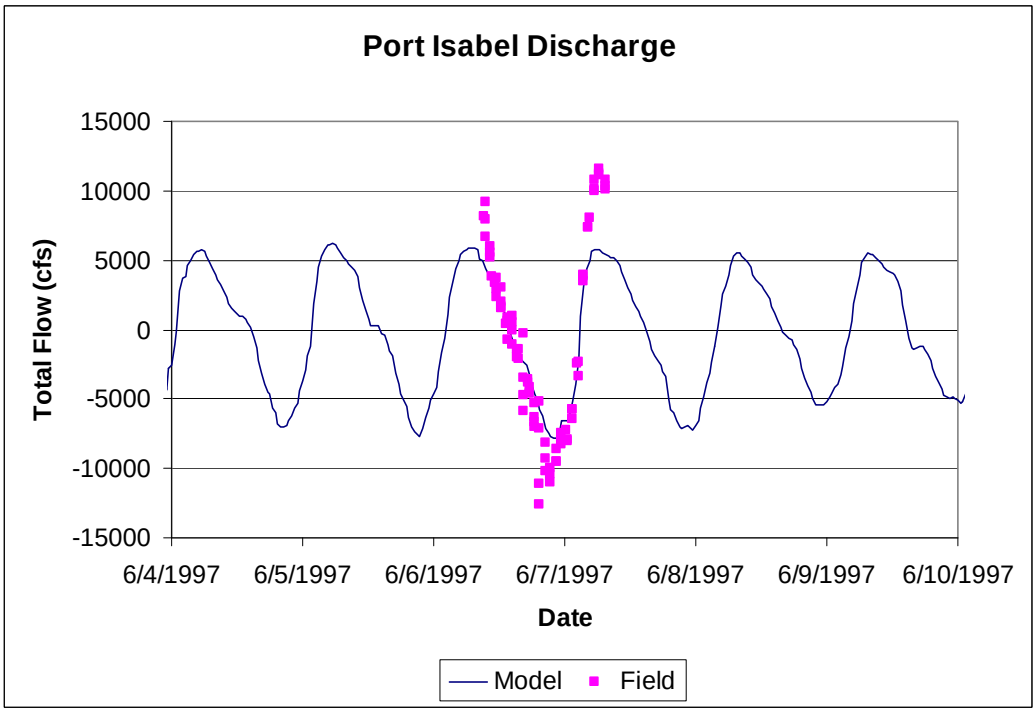

Figure 15. Discharge comparison at Port Isabel for June 1997.

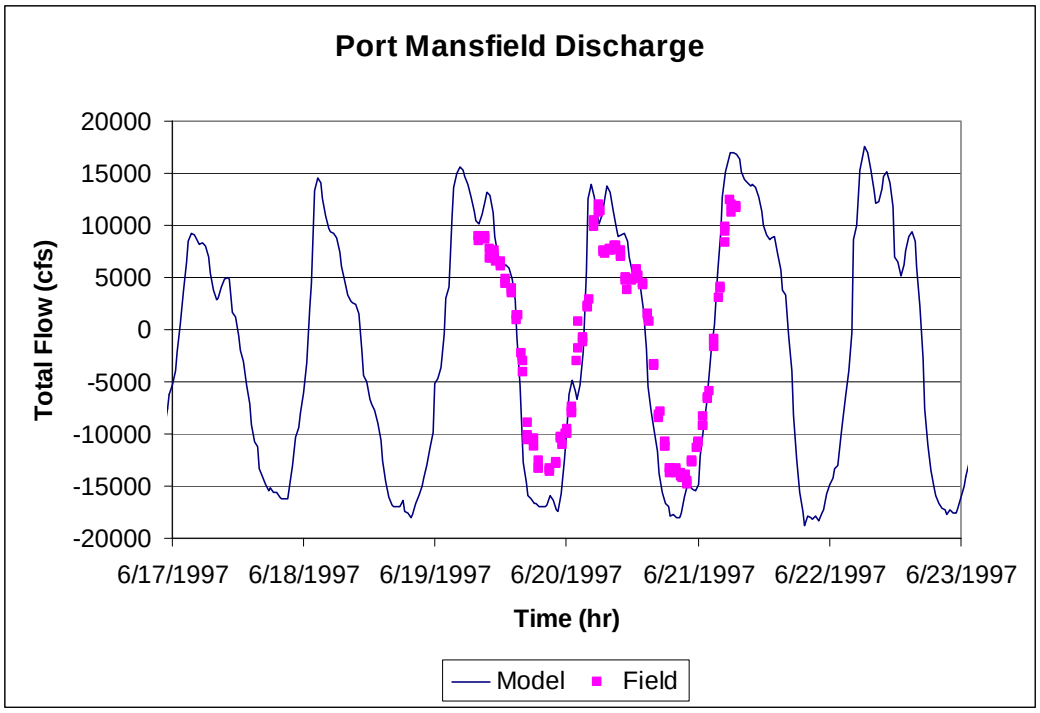

Figure 16. Discharge comparison at Port Mansfield for June 1997.

Figure 17. Water surface elevation comparison locations.

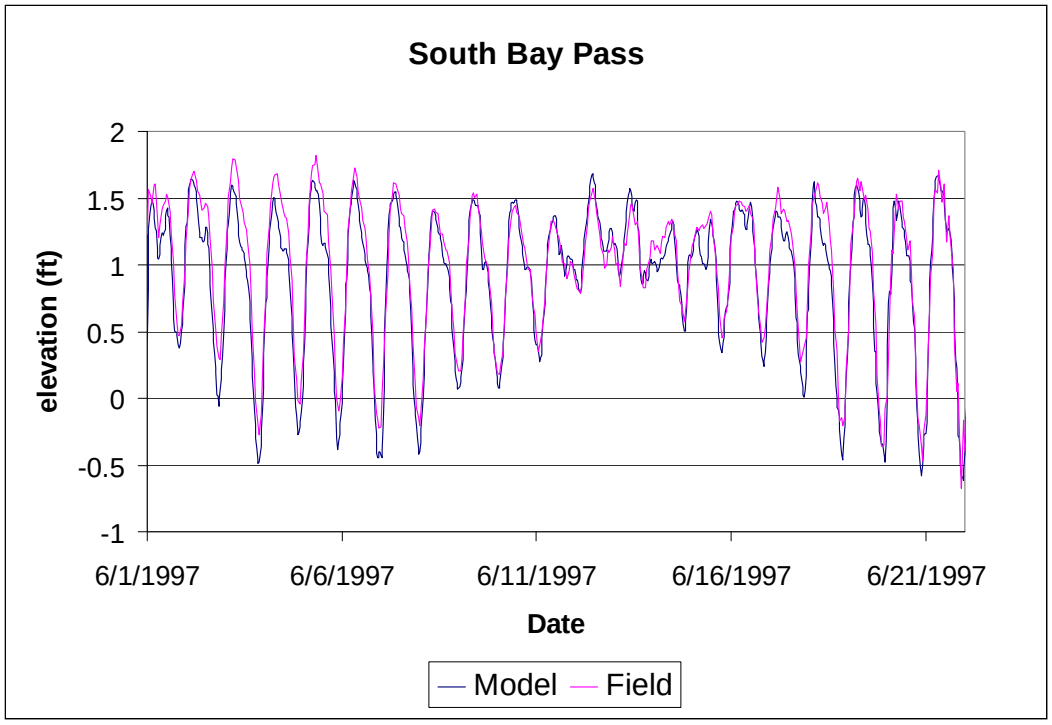

Figure 18. Water surface elevation comparison at South Bay for June 1997.

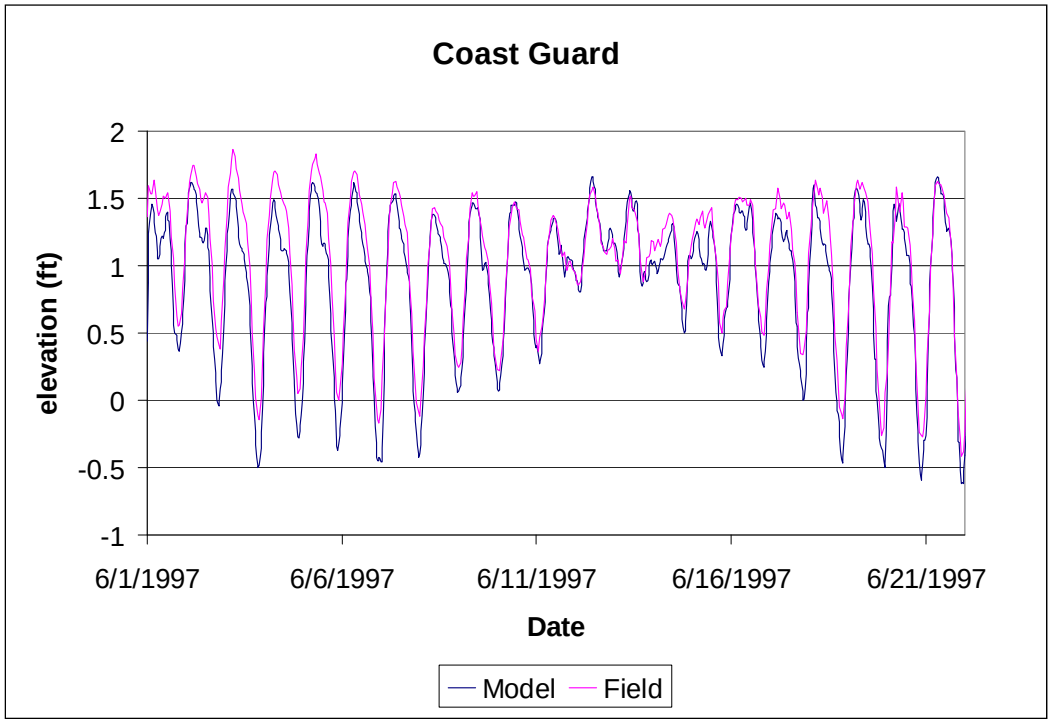

Figure 19. Water surface elevation comparison at Coast Guard for June 1997.

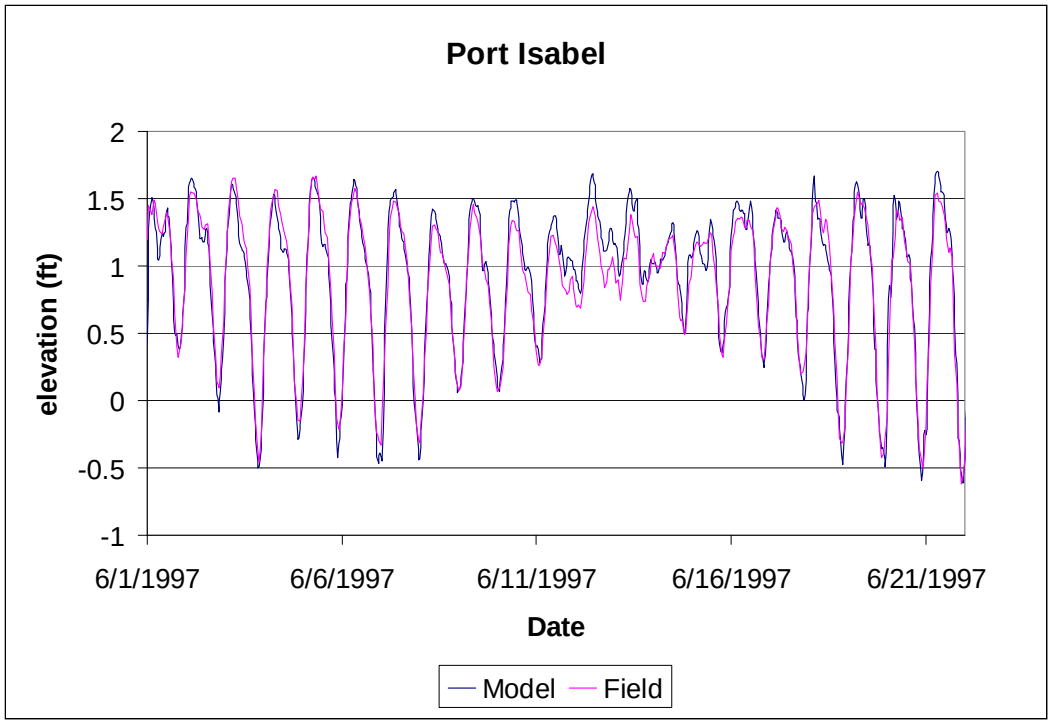

Figure 20. Water surface elevation comparison at Port Isabel for June 1997.

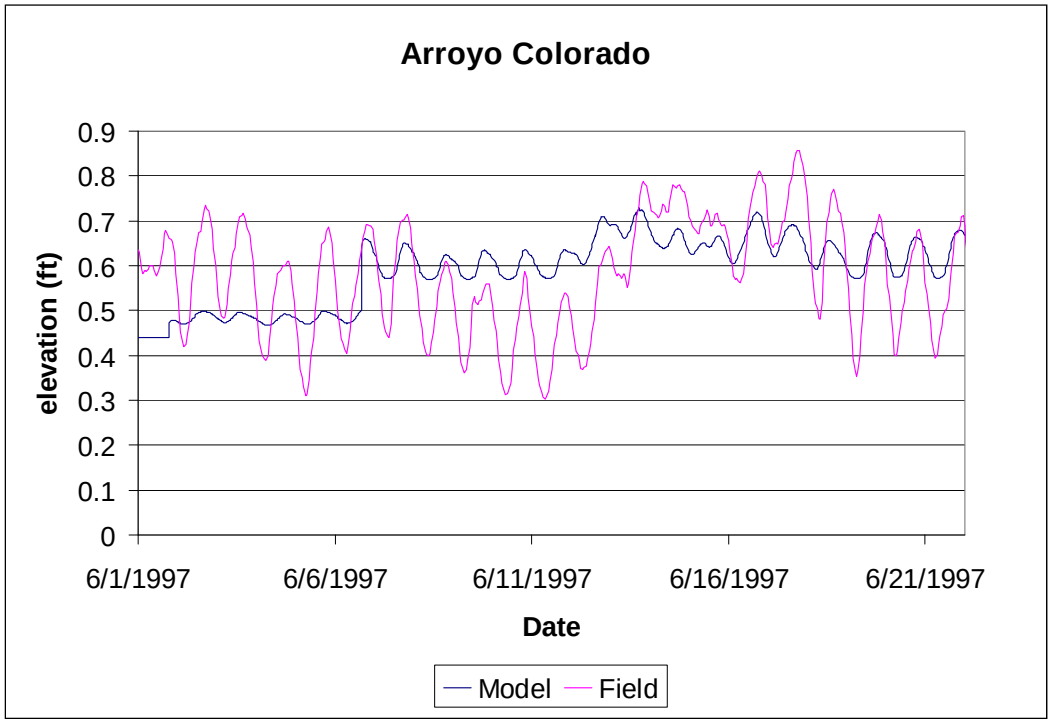

Figure 21. Water surface elevation comparison at Arroyo Colorado for June 1997.

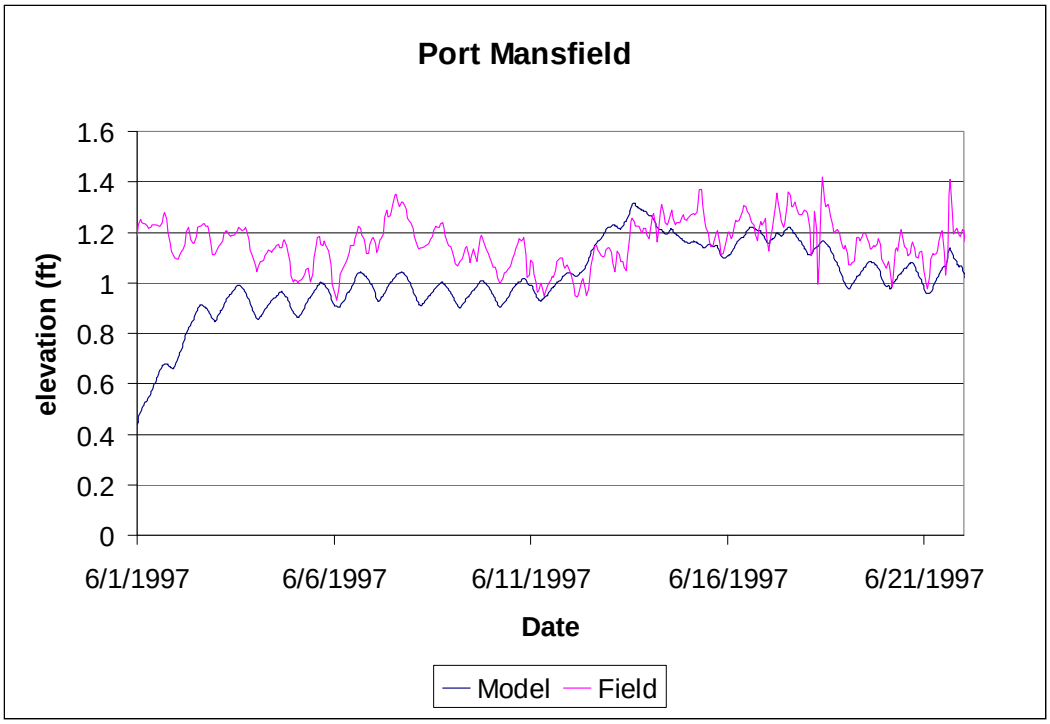

Figure 22. Water surface elevation comparison at Port Mansfield for June 1997.

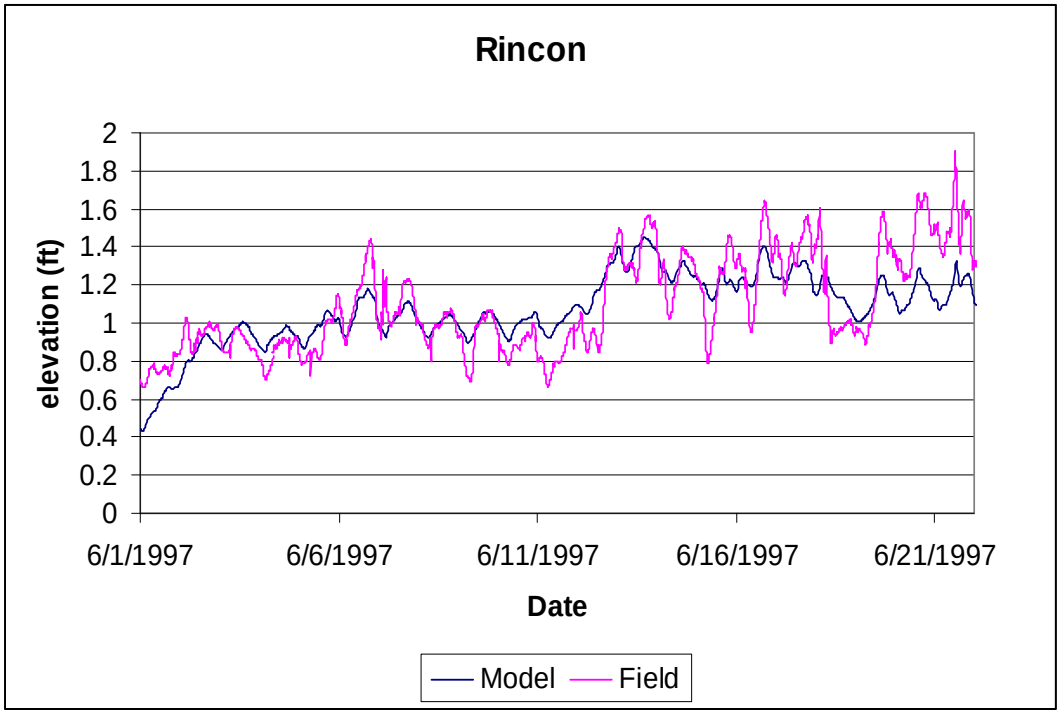

Figure 23. Water surface elevation comparison at Rincon for June 1997.

3.2 Roughness parameters

Through the validation process, a set of roughness parameters was determined such that the model yields the best representation of the field data.

These parameters were initially set according to the study documented in Teeter et al. 2003[11] and then adjusted within acceptable limits to better represent the field data. For this model, a Manning's formula approach was used for the bed roughness, and the friction varies spatially over the domain. In the shallow areas the model is more sensitive to these roughness parameters than in the deeper, channelized regions. AdH uses a roughness algorithm that equates the Manning's roughness value to an estimated roughness height of the bed. By doing this, AdH is able to represent any changes in roughness effects due to the depth of the water on a physical basis, as opposed to other methods that apply an additional algorithm requiring user input to make these adjustments. Figure 24 gives the spatial definition and Table 1 gives the Manning's coefficients for the various locations within the model domain. Sensitivity simulations were performed such that the Manning's values were adjusted in the ship channel, Bahia Grande, and South Bay but the model was determined to be insensitive to this parameter when modified within an acceptable range. The areas labeled as "disabled" are locations that were removed during the numerical computations. These areas either remain dry during the simulation or have very little effect on the system response in our area of interest, the Brownsville Ship Channel.

Table 1. Manning's roughness coefficients.

Area	Manning's Coefficient
1	0.02
2	0.035
3	0.03
4	0.023
5	0.038
6	Disabled

[11] Teeter et al., *Wind-Wave Resuspension*, January 2003.

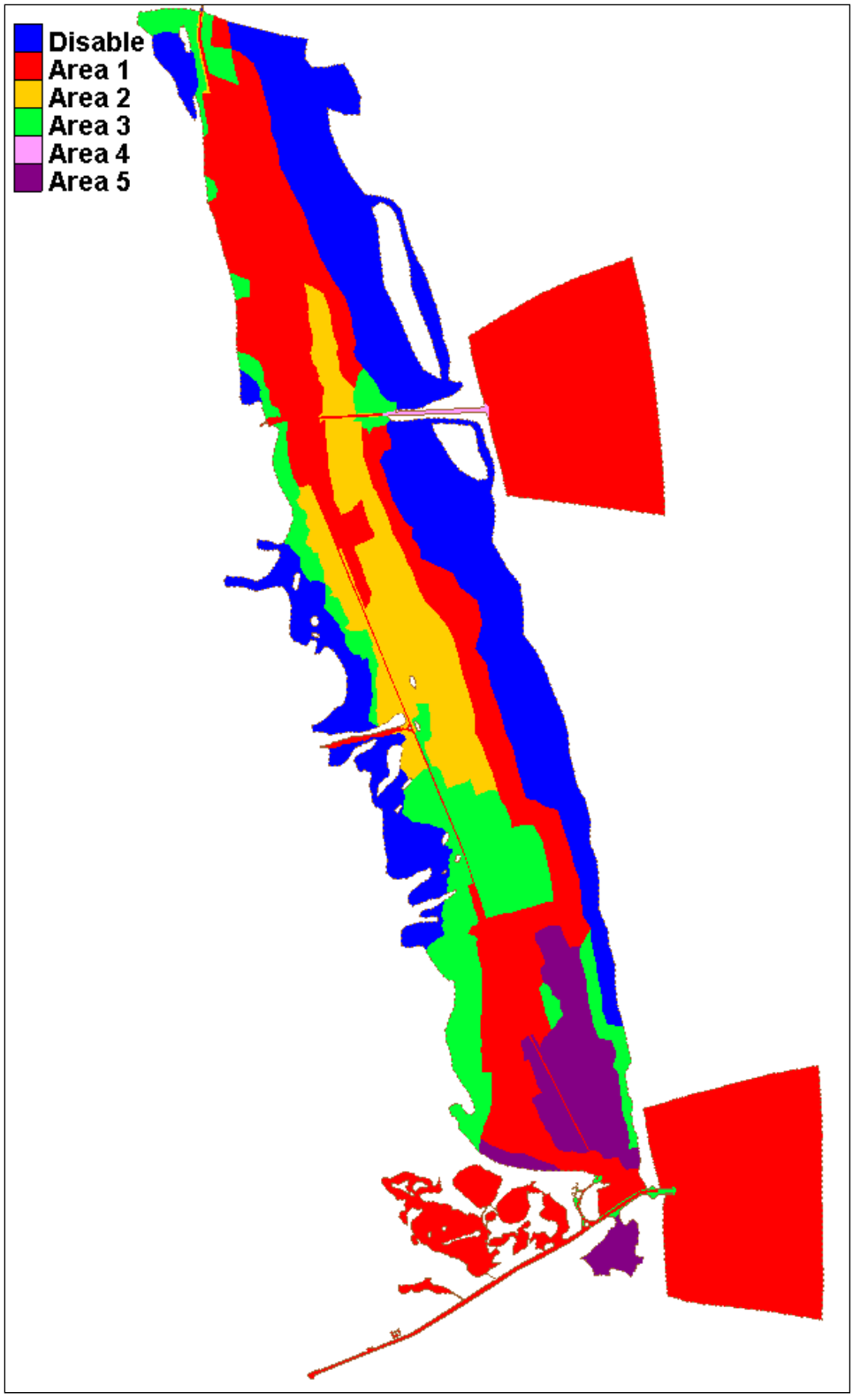

Figure 24. Manning's roughness coefficient definition.

4 Plan Simulation Results

The June 1997 boundary conditions were simulated for the Base and 12 plan configurations for the Brownsville Ship Channel. The Base is the 1997 mesh configuration, which does not include the Bahia Grande. The plans also do not include that area. For reference, the plan configurations are:

- Initial-Plan 1 – widen the channel by 200 ft (450 ft total width) using the design depth of 42 ft (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- Initial-Plan 2 – widen the channel by 200 ft (450 ft total width) and deepen to 45 ft (with 3 ft of overdredge and advanced maintenance for a 48 ft total depth)
- Initial-Plan 3 – widen the channel by 200 ft (450 ft total width) and deepen to 48 ft (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- S26-Plan1 – widen the channel by 200 ft (450 ft total width) from mouth to Station 26 and maintain the design depth of 42 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- S26-Plan2 – widen the channel by 200 ft (450 ft total width) and deepen to design depth of 45 ft from mouth to Station 26 and maintain the design depth of 42 ft the remaining extent of the channel (with 3 ft of overdredge and advanced maintenance for 48 and 45 ft total depths, respectively)
- S26-Plan3 – widen the channel by 200 ft (450 ft total width) and deepen to design depth of 48 ft from mouth to Station 26 and maintain the design depth of 42 ft the remaining extent of the channel (with 3 ft of overdredge and advanced maintenance for 51 and 45 ft total depths, respectively)
- Deepen Only-Plan 1 – maintain the design depth of 42 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 45 ft total depth)
- Deepen Only-Plan 2 – deepen to 45 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 48 ft total depth)
- Deepen Only-Plan 3 – deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)

- Plan-300 ft – widen the channel by 50 ft (300 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- Plan-350 ft – widen the channel by 100 ft (350 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)
- Plan-400 ft – widen the channel by 150 ft (400 ft total width) and deepen to 48 ft the entire extent of the channel (with 3 ft of overdredge and advanced maintenance for a 51 ft total depth)

The results of these simulations are provided for ship simulation analysis to determine how the changes to the hydrodynamics affect navigation.

4.1 Base condition for plan comparisons

The plan results are compared to a Base condition such that the channel is in its previous design condition, 250 ft wide with a 42 ft depth (with an additional 3 ft of overdredge and advanced maintenance). The District attempts to maintain these design conditions with maintenance dredging operations, which supports the use of this condition as the Base, as opposed to the current channel condition, which has undergone some shoaling. However, to verify that the 2007 survey of the channel and the design Base conditions (referred to, respectively, as Base 2007 and Base 250) produce comparable results and ensure that the results obtained from the plan comparisons are reasonable, both conditions are simulated with the model, and the discharge and velocity magnitudes are compared. Figure 25 shows the locations for these comparisons. Results for this single cross-section, over one day, are shown in Figures 26–28. The discharge comparison (Figure 26) shows flow leaving the channel and entering the Gulf of Mexico as negative values, and flow directed into the channel as positive values, consistent with typical flood/ebb convention. The two channel dimensions produce very similar discharge patterns and direction of flow. The velocity plots (Figures 27 and 28) are shown as positive values for flood directed flow and negative values for ebb flow. These results are shown for the center location and a location to the north and south along the channel side slopes (Figure 25). The velocity magnitudes differ slightly, yet the general flood/ebb pattern is the same for the two channel dimensions. Since the differences between these base conditions are small, using the design condition (Base 250) as the Base will not adversely affect the plan comparison results.

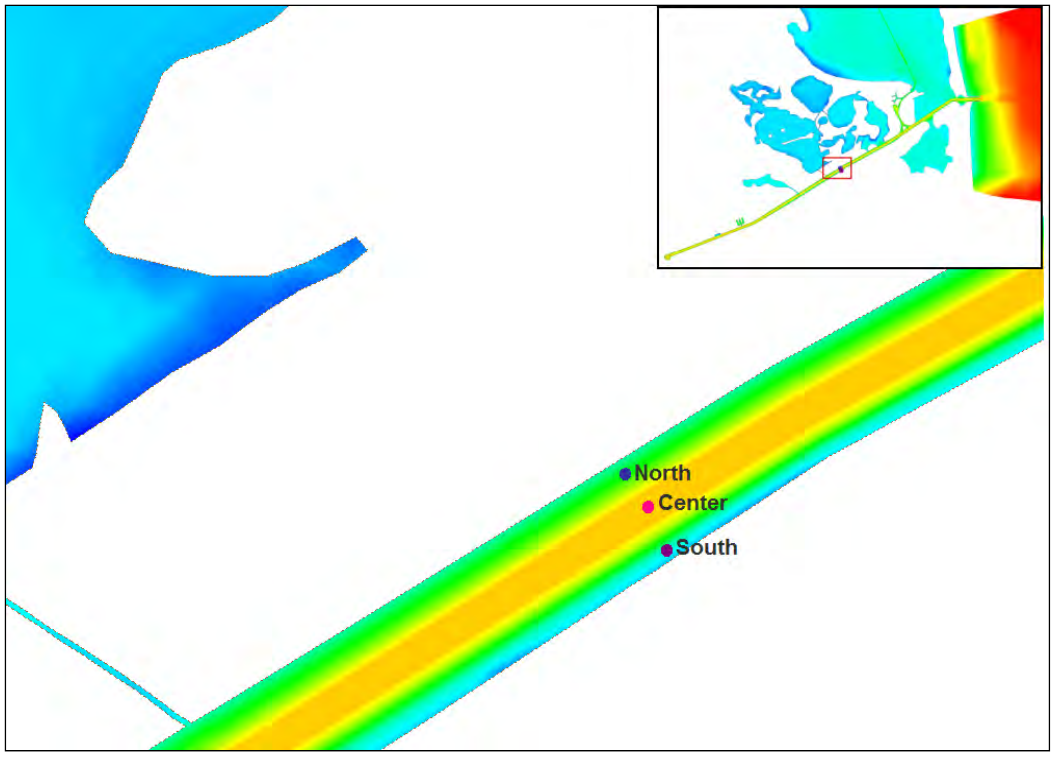

Figure 25. Location of design configuration and 2007 survey configuration Base results.

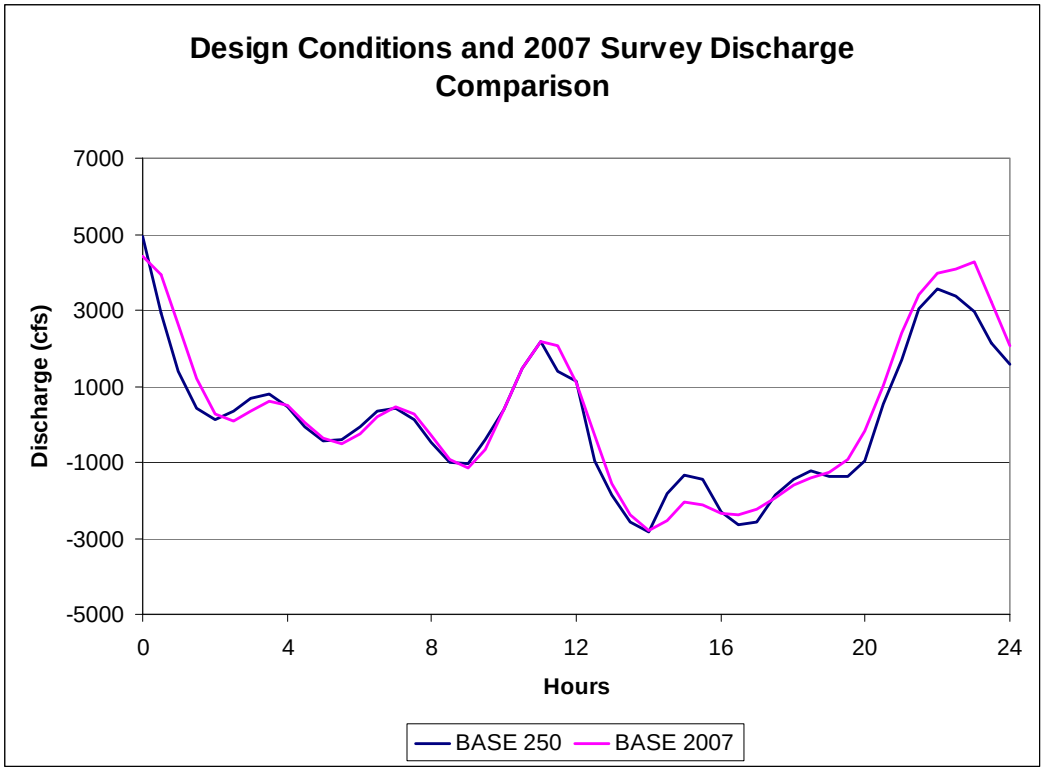

Figure 26. Comparison of discharge for the 2007 survey and the 250 x 42 ft design conditions of the channel.

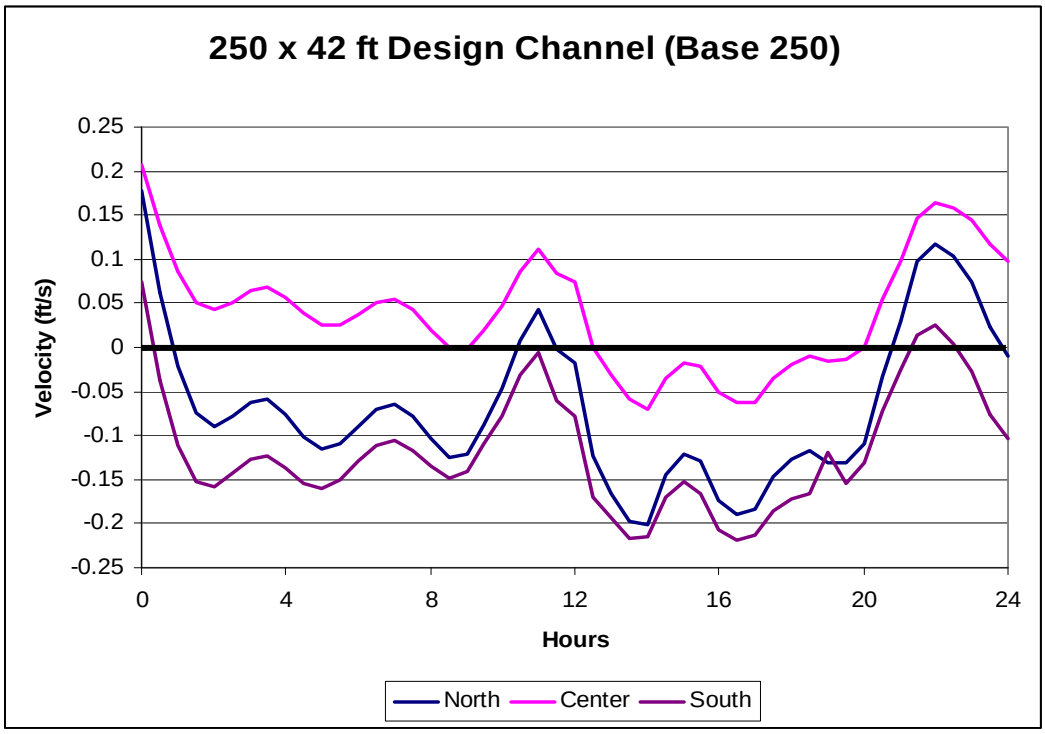

Figure 27. Velocity magnitude and direction across the channel for the 250 x 42 ft design condition.

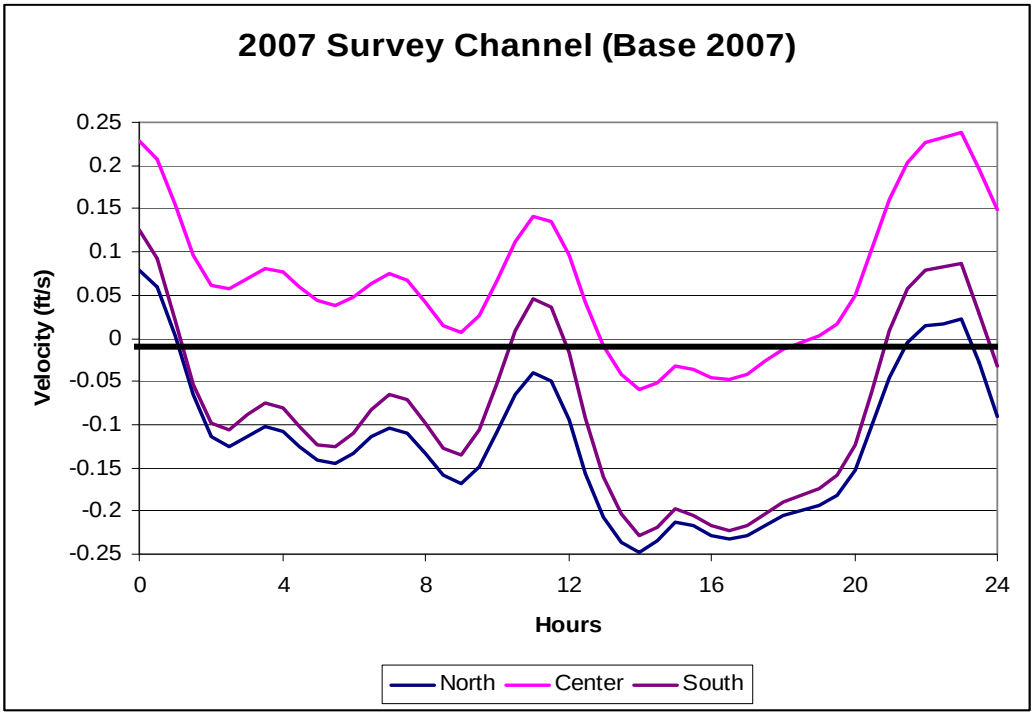

Figure 28. Velocity magnitude and direction across the channel for the 2007 survey condition.

4.2 Base and plan comparisons

Discharge comparisons between Base and Plan conditions are made at the arc locations shown in Figure 29. Velocity magnitudes and direction, percent exceedance, and water surface elevations were compared at several locations along the ship channel and in the Laguna Madre. Figures 30 and 31 show the locations of these analysis points. Figures 32 – 43 show the results of the discharge comparisons over 5 days where negative values are directed toward the Gulf (ebb) and positive values indicate inland-directed flow (flood). Velocity and water surface comparisons are given for the points along the centerline of the ship channel, whereas only water surface comparisons are made for the Laguna Madre locations. The velocity data are presented in typical flood (inland flow) and ebb (seaward flow) directed convention. The conditions for the SWG Initial plan set are presented with the Base results on a single plot; the Station 26 results are presented with the Base results on a second plot; the Deepen Only results are presented with the Base on a third plot; and the 300/350/400 ft results are presented with the Base on a fourth plot.

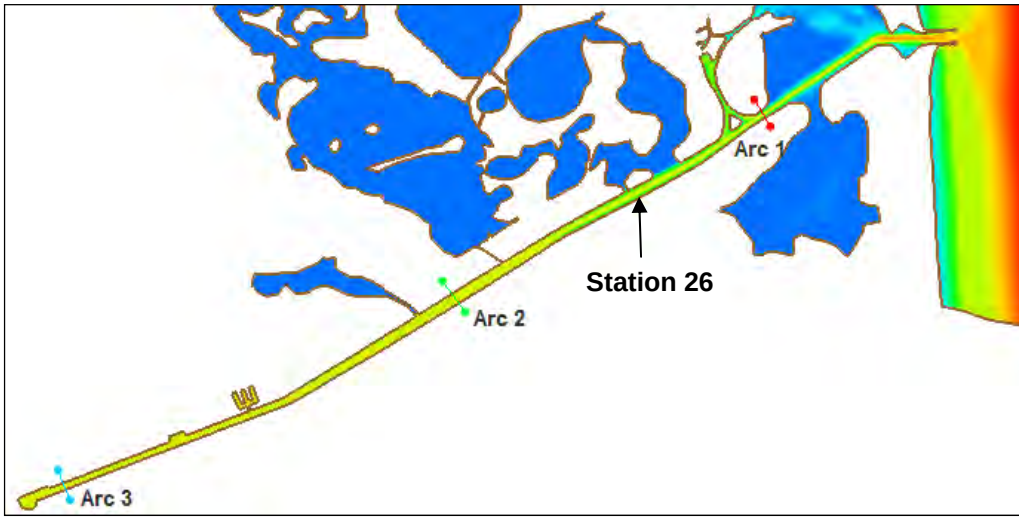

Figure 29. Discharge comparison locations.

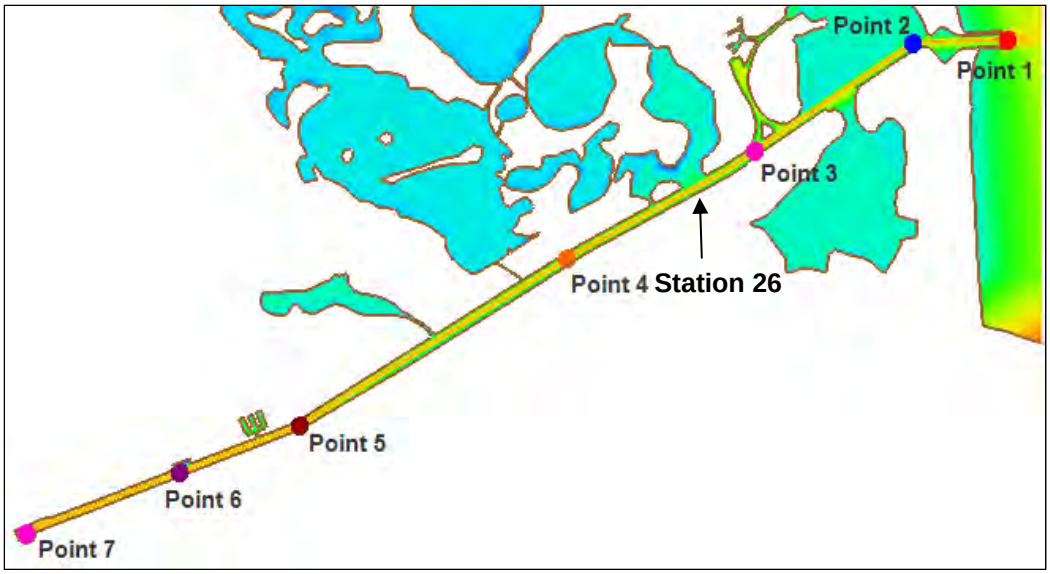

Figure 30. Brownsville Ship Channel analysis locations.

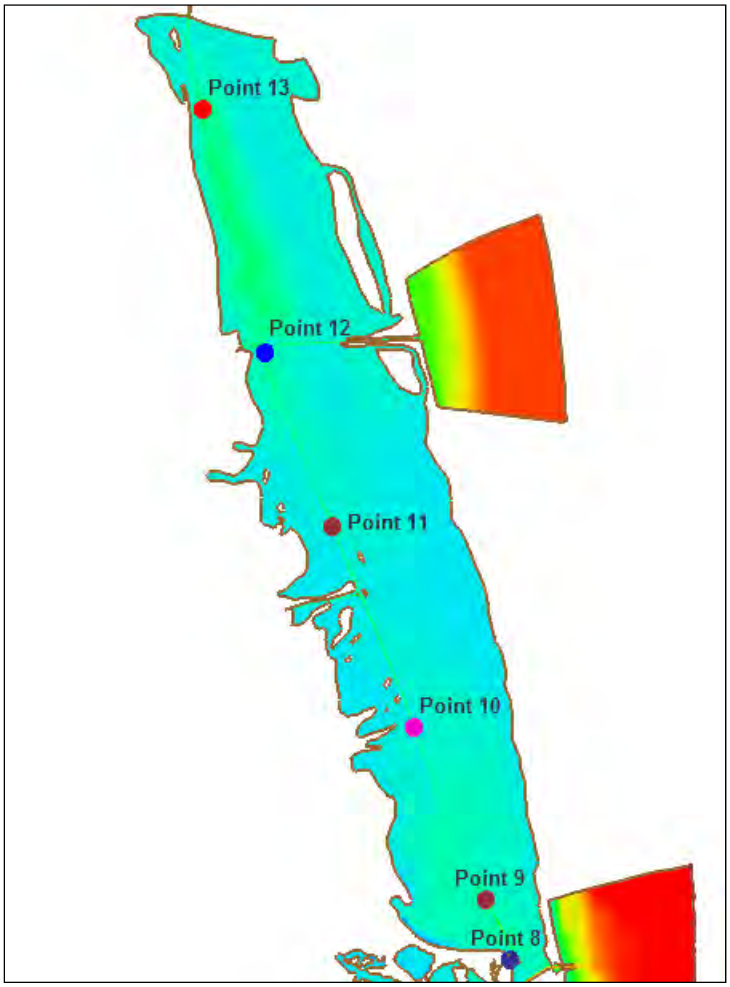

Figure 31. Laguna Madre analysis locations.

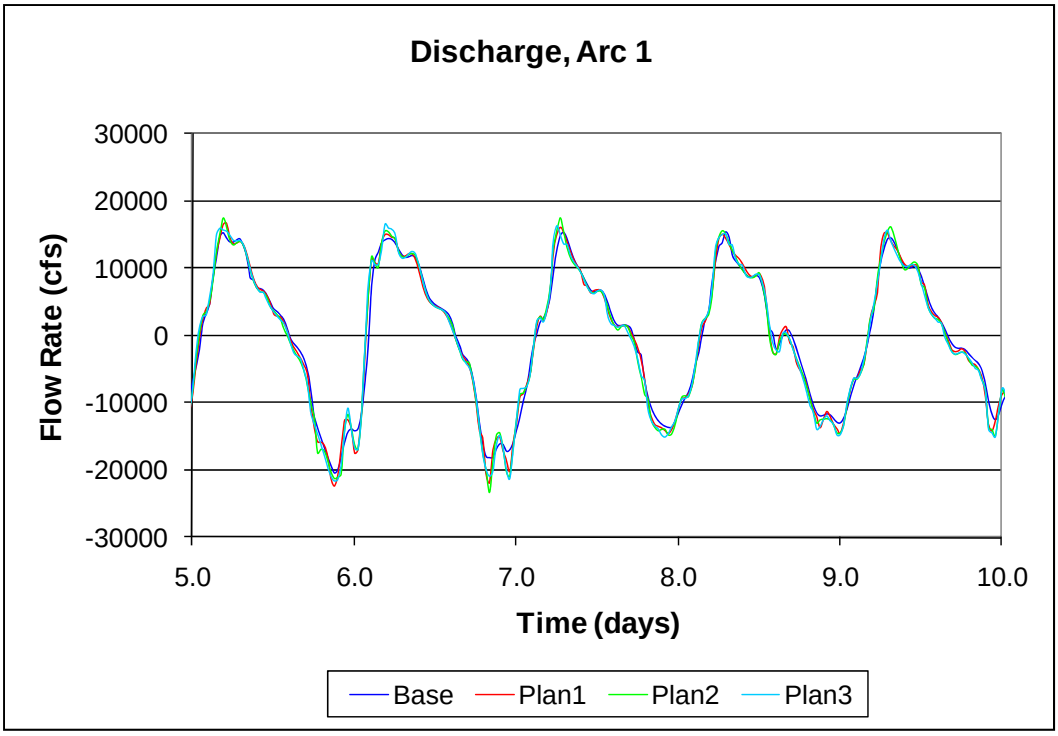

Figure 32. Discharge comparison for arc 1 for Initial plan set.

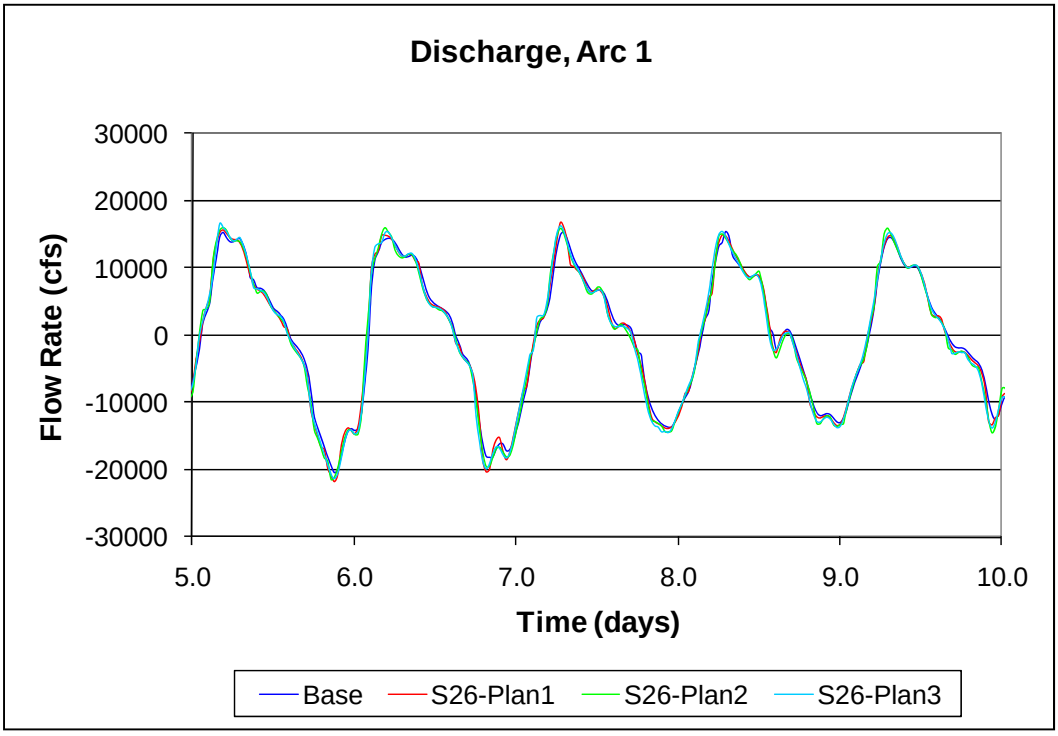

Figure 33. Discharge comparison for arc 1 for Station 26 plan set.

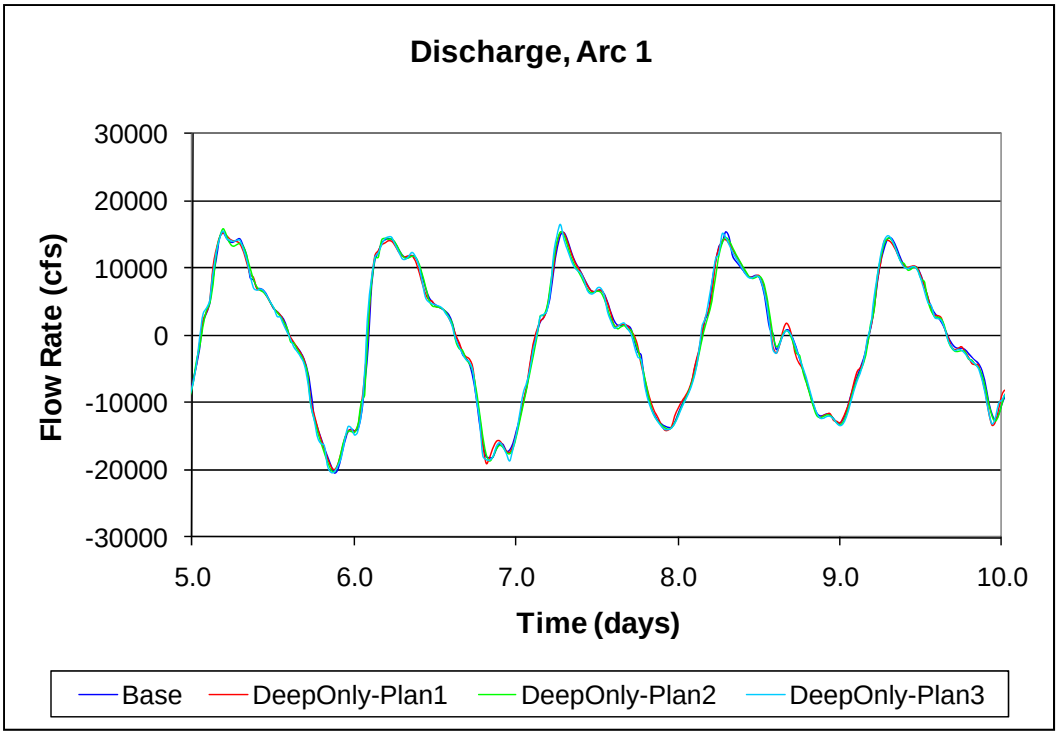

Figure 34. Discharge comparison for arc 1 for Deepen Only plan set.

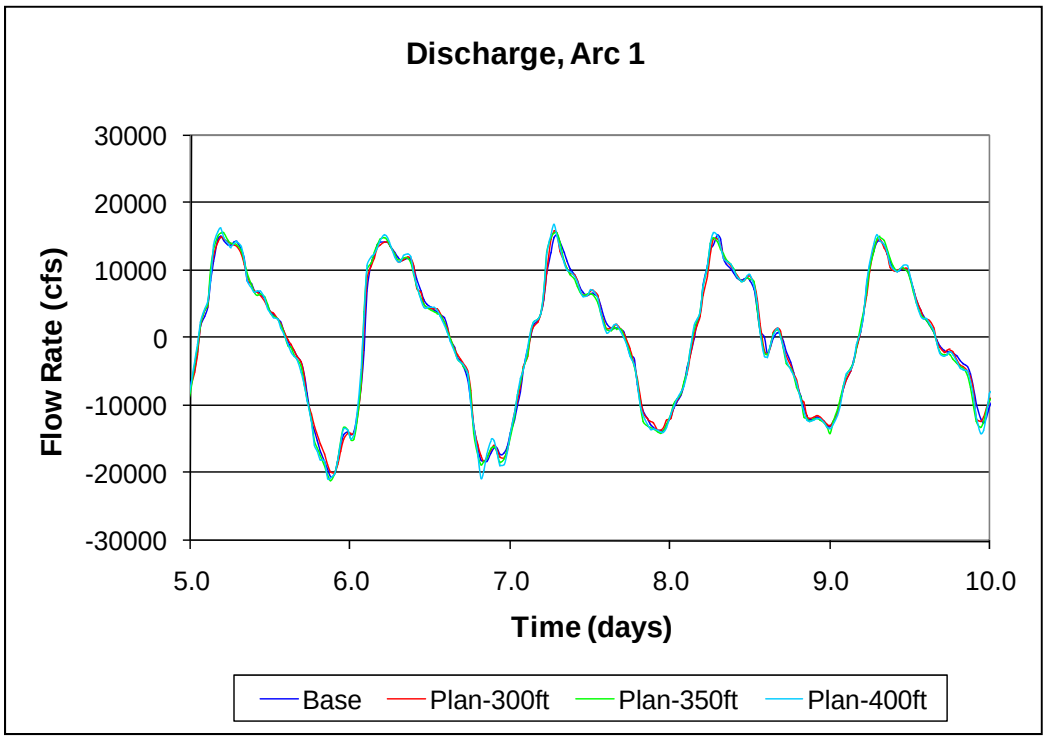

Figure 35. Discharge comparison for arc 1 for 300/350/400 plan set.

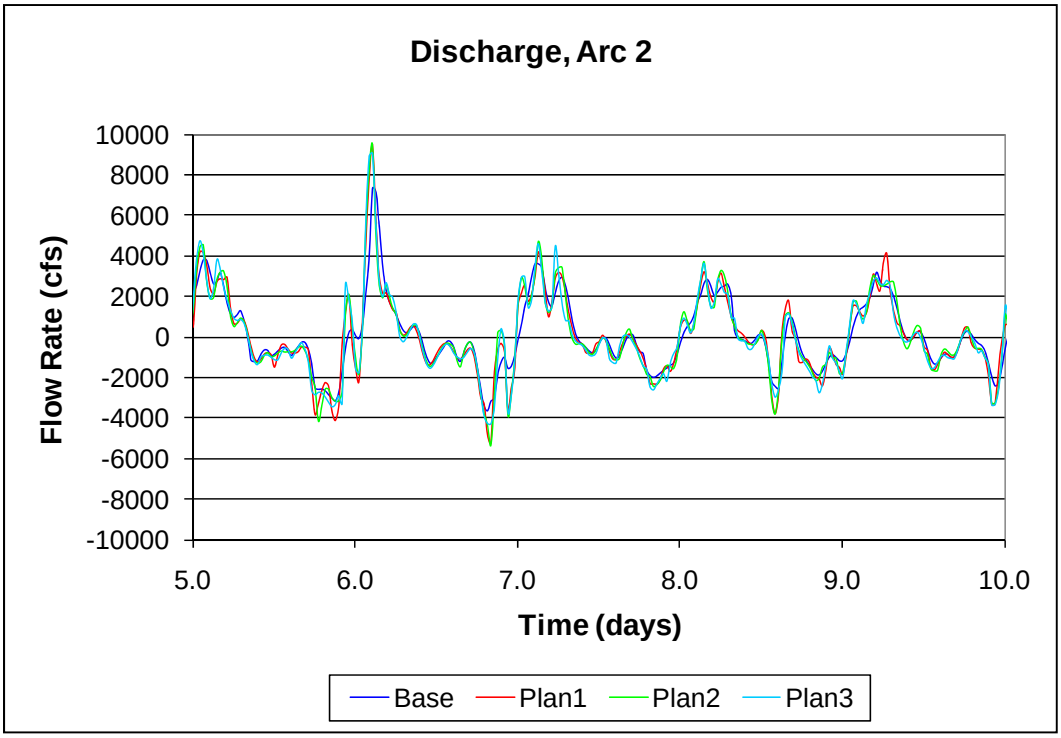

Figure 36. Discharge comparison for arc 2 for Initial plan set.

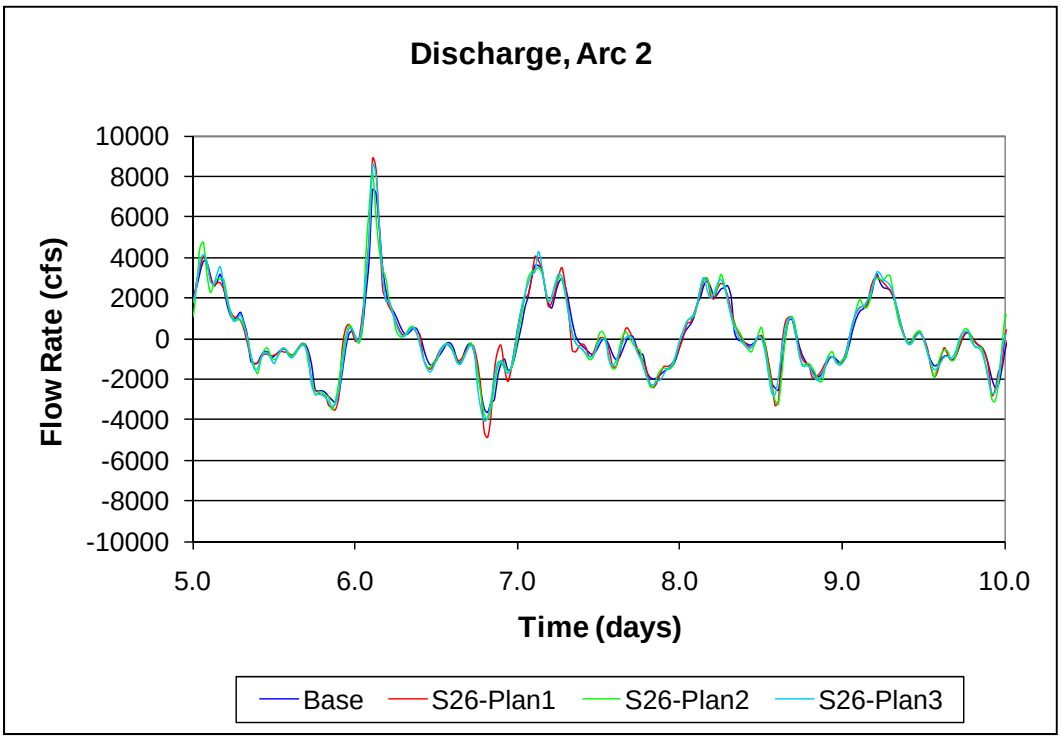

Figure 37. Discharge comparison for arc 2 for Station 26 plan set.

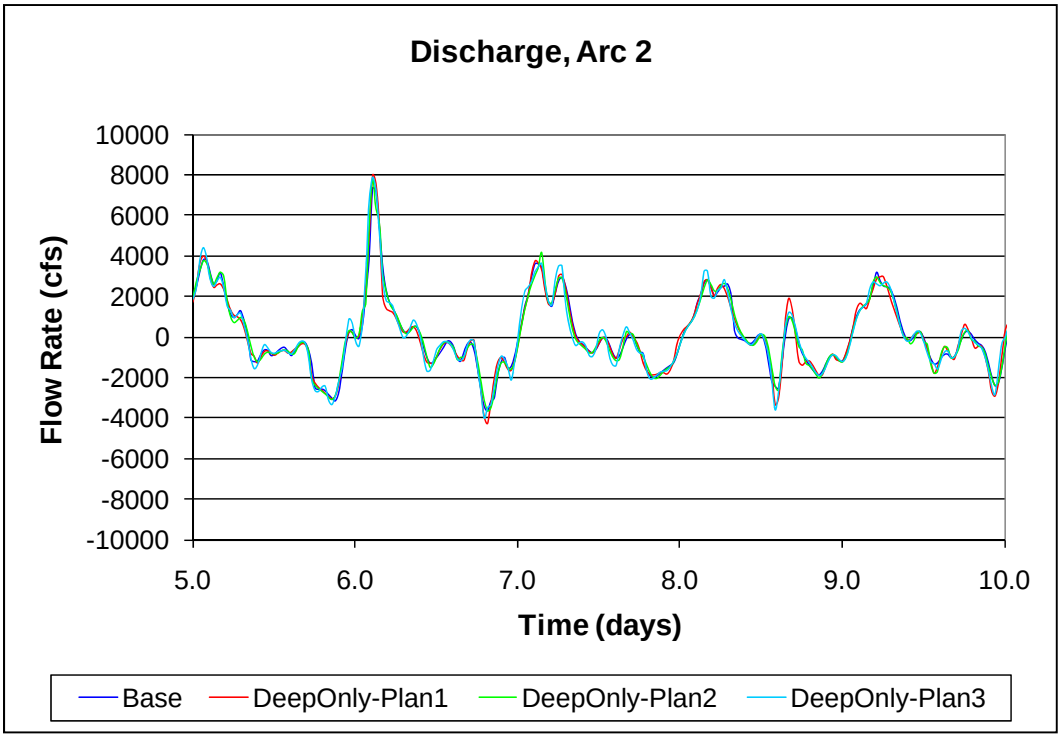

Figure 38. Discharge comparison for arc 2 for Deepen Only plan set.

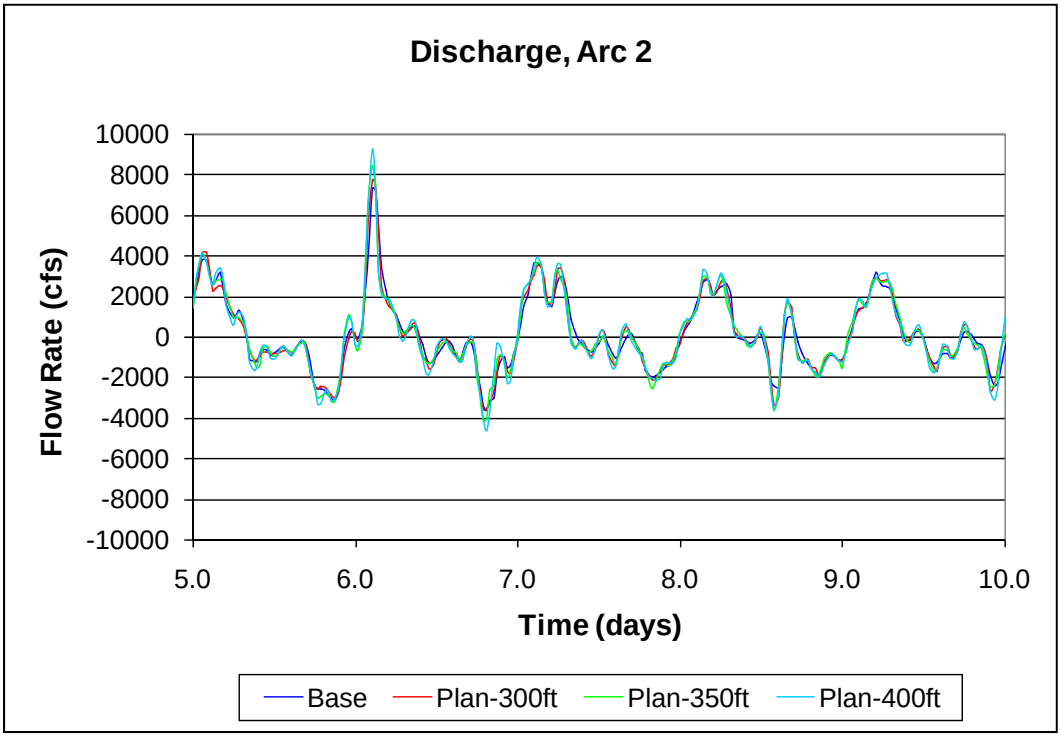

Figure 39. Discharge comparison for arc 2 for 300/350/400 plan set.

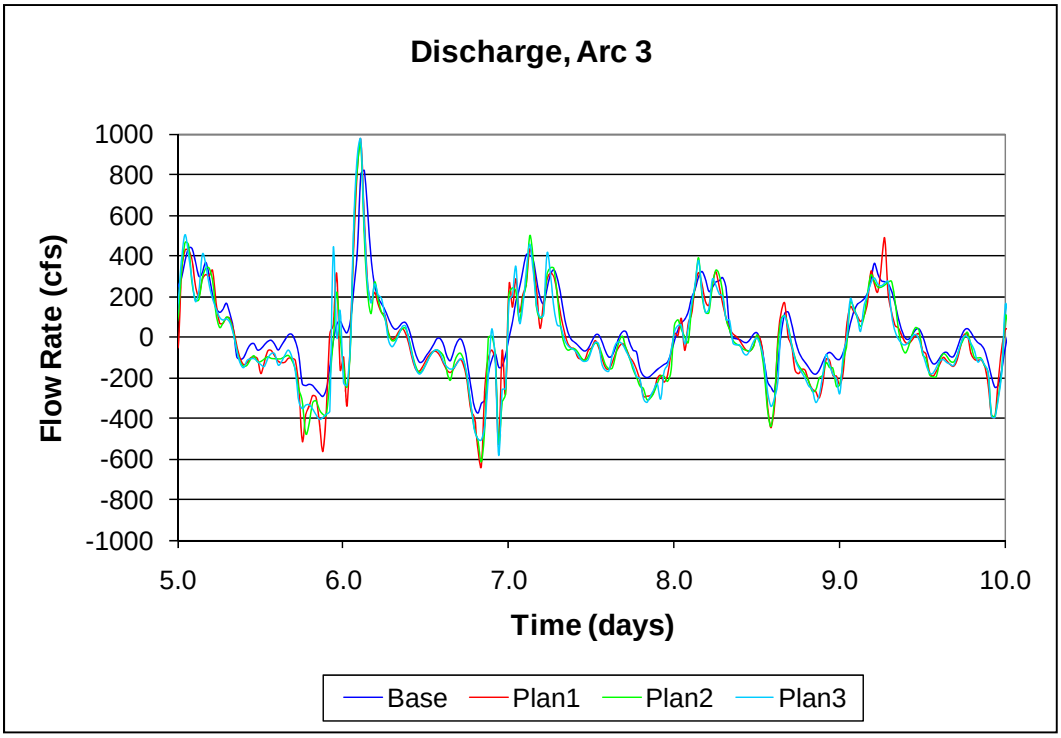

Figure 40. Discharge comparison for arc 3 for Initial plan set.

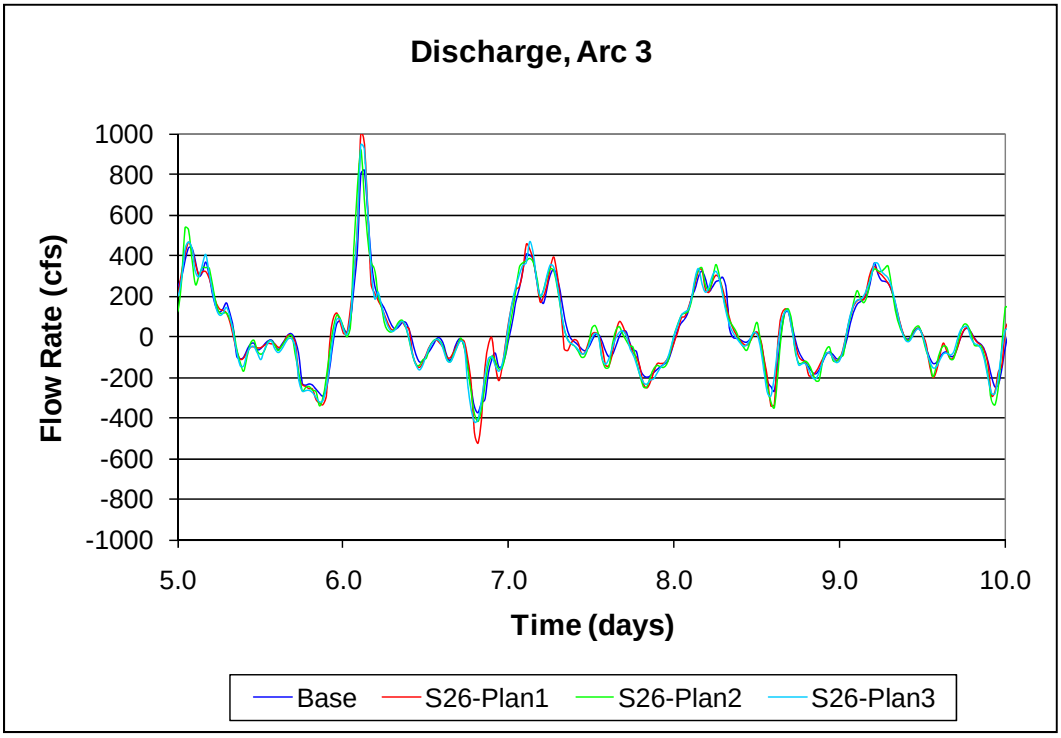

Figure 41. Discharge comparison for arc 3 for Station 26 plan set.

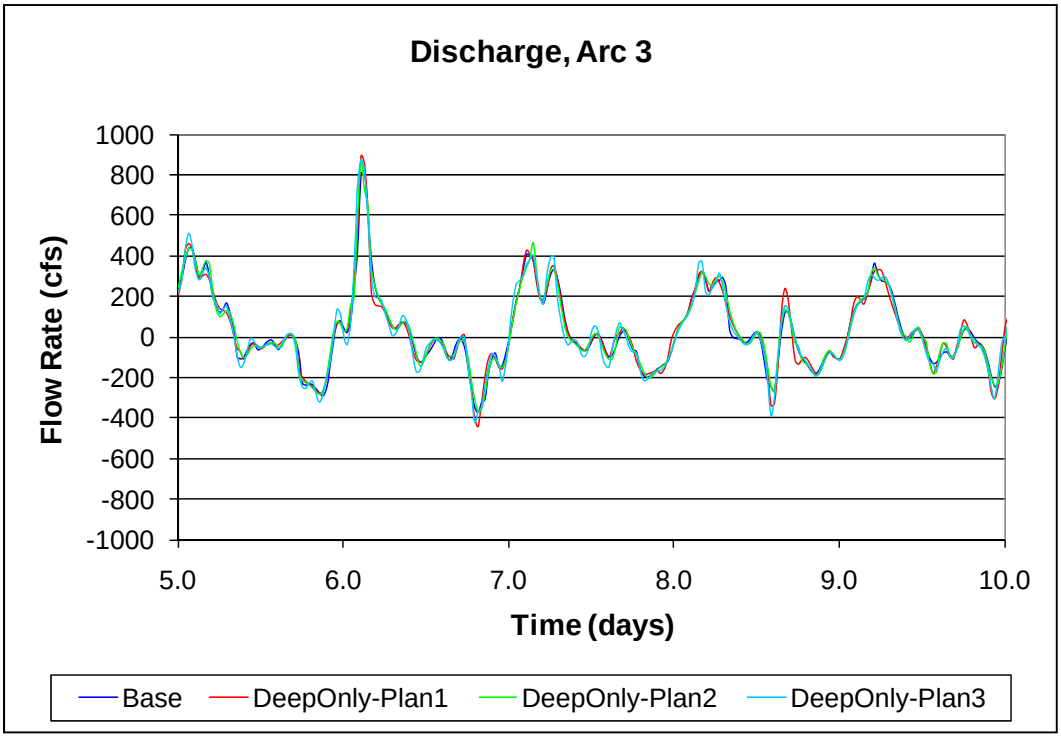

Figure 42. Discharge comparison for arc 3 for Deepen Only plan set.

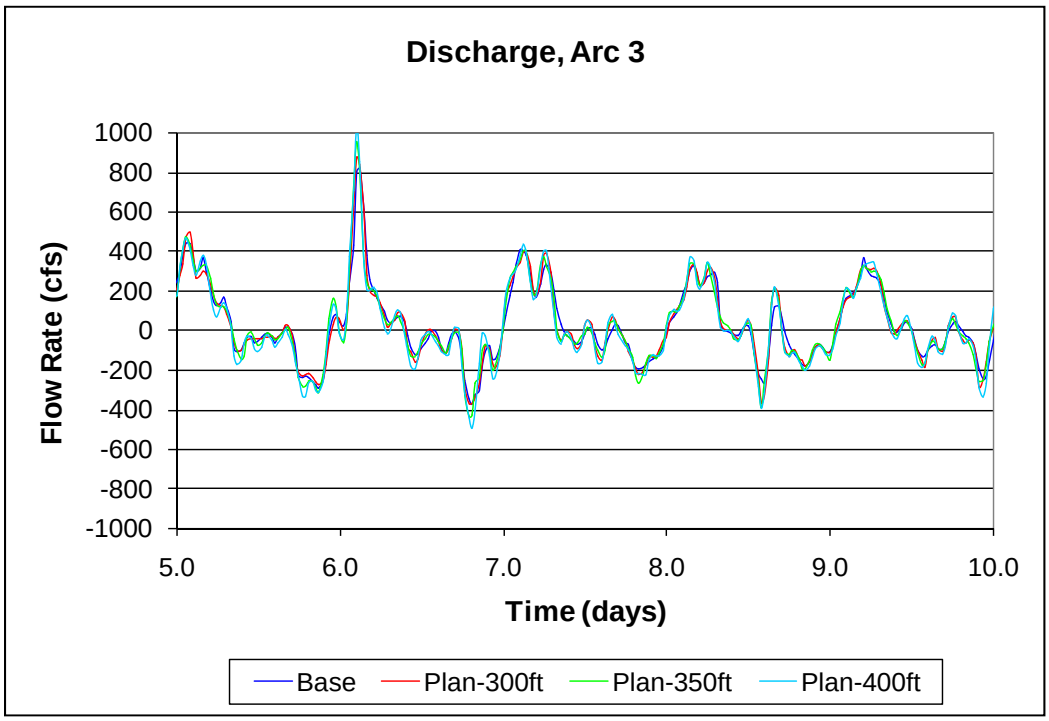

Figure 43. Discharge comparison for arc 3 for 300/350/400 plan set.

4.2.1 Discharge comparisons

The discharge comparisons indicate that the deepening only and the deepening and widening to Station 26 have a smaller effect on the discharge

than the complete channel deepening and widening. The 300/350/400 ft plan set with less widening but deepening the entire channel to 52 ft shows some slightly larger variations in discharge, but still affects the discharge less than the full-extent 200 ft widening options.

At Arc 1 closest to the Gulf of Mexico, results for the Initial plan set (i.e., Plans 1, 2, and 3) show higher ebb directed discharges than with no changes to the system. The Station 26 plans also show an increase but it is less for these conditions and the Deepen Only plans show essentially no change. The 300/350/400 ft plan set shows results similar to the Station 26 plan results in that there is some change from the Base condition but it is noticed mostly on the peak ebb flows. The flood-directed flows are affected in the same manner but on a smaller scale in general.

At Arc 2 the flows are lower overall, and the Station 26 plans follow the same pattern as the Base with only slight increases in the discharge extremes. The Deepen Only plans show the same variations as the other plans, and the differences are small. The 300/350/400 ft plans show variation in discharge from the Base with increased magnitudes in the flood and ebb direction correlated to the increase in the channel width, i.e., the wider the channel the larger the difference in general. Plans 1, 2, and 3, however, show larger changes from the Base in terms of a small shift in the phasing and in the magnitude of the peak flood and ebb flows.

The final location, Arc 3 near the turning basin, shows similar results to those at Arc 2. The Station 26 plans undergo fewer effects due to the changes in the channel although the peak flows are increased some and the same is seen for the Deepen Only plans. The 300/350/400 ft plans show slightly more variation from the Base discharge values, but the phasing is consistent and the same correlation of discharge to channel width remains as with Arc 2. Plans 1, 2, and 3 show higher peak flows from the Base as well as a general time shift such that the peak flows arrive earlier with the deeper channel, by a maximum of 30 minutes.

It is interesting to note that the same depth is used for Plan 3 and for the 300/350/400 ft plans, and the latter plans do not indicate the phase shift or as large a variation from the Base. This indicates that the larger channel widening of 200 ft has a greater impact on the discharge in the channel than the deepening. It also indicates that a 100 ft increase in channel width generates minor effects when compared with a 200 ft increase.

4.2.2 Velocity comparisons

Figures 44 – 123 show velocity magnitude and direction during day 15 and day 29 of the simulation as well as percent exceedance of velocity for each of the ship channel locations. Positive velocity values indicate flood-directed flow, or flow into the channel from the Gulf of Mexico; negative values indicate ebb-directed flow, or flow leaving the channel. The percent exceedance plots show how often a given velocity magnitude is reached during the analysis period. For these simulations, this period includes the entire month of June 1997. At 100% on the y-axis, the velocity is zero at the specific location, meaning that the velocities exceed zero 100% of the time. At 50%, the velocity value is greater half the time and less than half the time. The velocity maximum is at 0% since the velocity magnitude will never exceed this value.

The most obvious revelation among these comparisons is that the velocity magnitudes reduce greatly from the Gulf of Mexico to the turning basin. At the Gulf, the velocity average is on the order of 1.0 ft/s, where the velocity at the turning basin is generally less than 0.02 ft/s. Generally speaking, channel widening results in smaller velocity magnitudes, as expected, since widening results in a much greater increase in cross section as compared with deepening. Also of note is that the direction of flow varies quite a bit from the Base for the plan conditions, primarily Plans 1 – 3 where the channel modifications extend the entire length of the Brownsville Ship Channel. The channel widening appears to be the cause for this change in flow direction from the Base condition since the Deepen Only conditions do not show this variation. At the turning basin, Point 7, the enlarged channel is generating large percentage changes from the Base in the form of lower velocity magnitudes, though all velocity magnitudes from Point 3 inward are, in absolute terms, small—on the order of less than 0.2 ft/s. These results will vary based on how the turning basin is modified in the final plan configuration. The greatest effect on the channel flows again appears to be the width increase.

Although the depth variation with each plan does affect the results, the impact is not as great as the width increase. The Station 26 plans show very close agreement to the Base condition at the points beyond Station 26, which indicates that the channel modifications up to this point do not greatly affect the remainder of the channel. The Deepen Only plans follow the same general velocity response as the Base, but there is a slight shift in the phasing of the flows and in the peak velocity magnitudes with the changes in depth. Beginning at Point 3, the depth of 48 ft (+3 ft) seems to

generate increased velocities when compared with the shallower depths for the Deepen Only condition. The shallower depths do not increase the flow area enough to see this effect like the deeper condition.

Due to the closed construction of this channel, changes in depth can affect the wave speed and the behavior of wave reflections. This is evident in the phasing difference between the Base and some plans at several locations. In widened conditions, the cross section has more deep areas than shallow, near-bank areas, which also contributes to alterations in the flow pattern (as discussed in the next paragraph). The 300/350/400 ft Plans give results similar to the Deepen Only Plan 3 condition since this depth is used in these additional three plans. However, the 50 ft change in the channel width generates larger differences from the Base condition at Points 4 and 5, especially during the day 29 comparison. The larger width increases of 100 and 150 ft generate higher velocities at Point 7. The width variation for the 300/350/400 ft Plans has a smaller effect on the velocity change from the Base at all other locations.

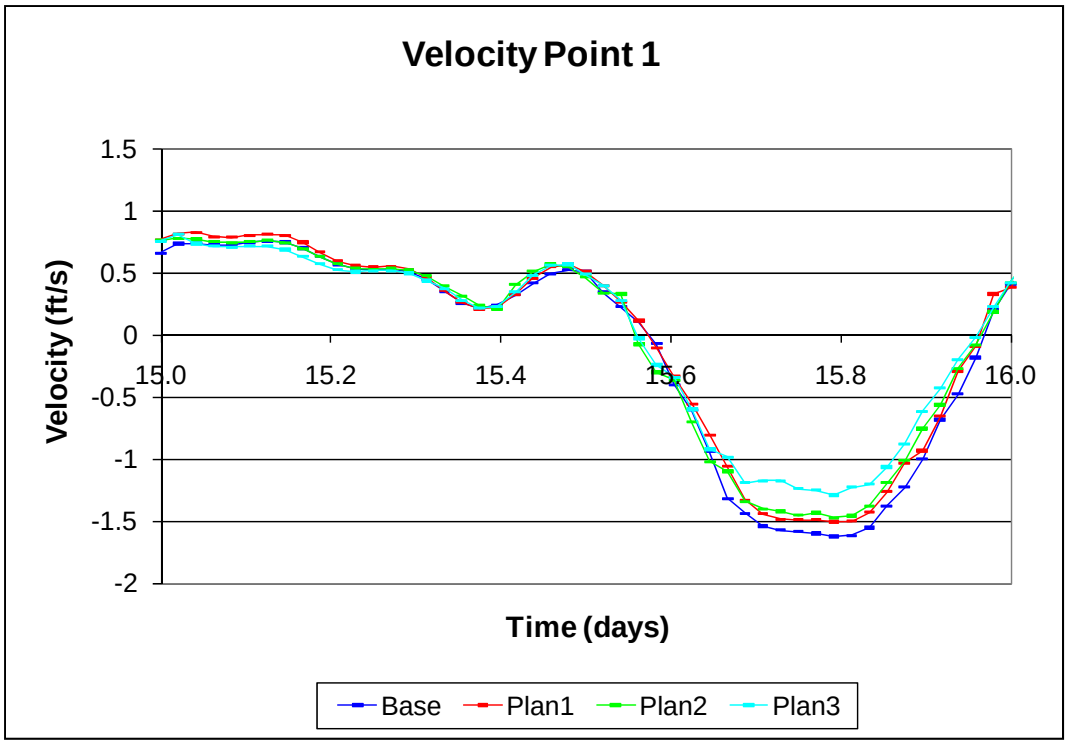

Figure 44. Velocity comparison for day 15 at point 1 for Initial plan set.

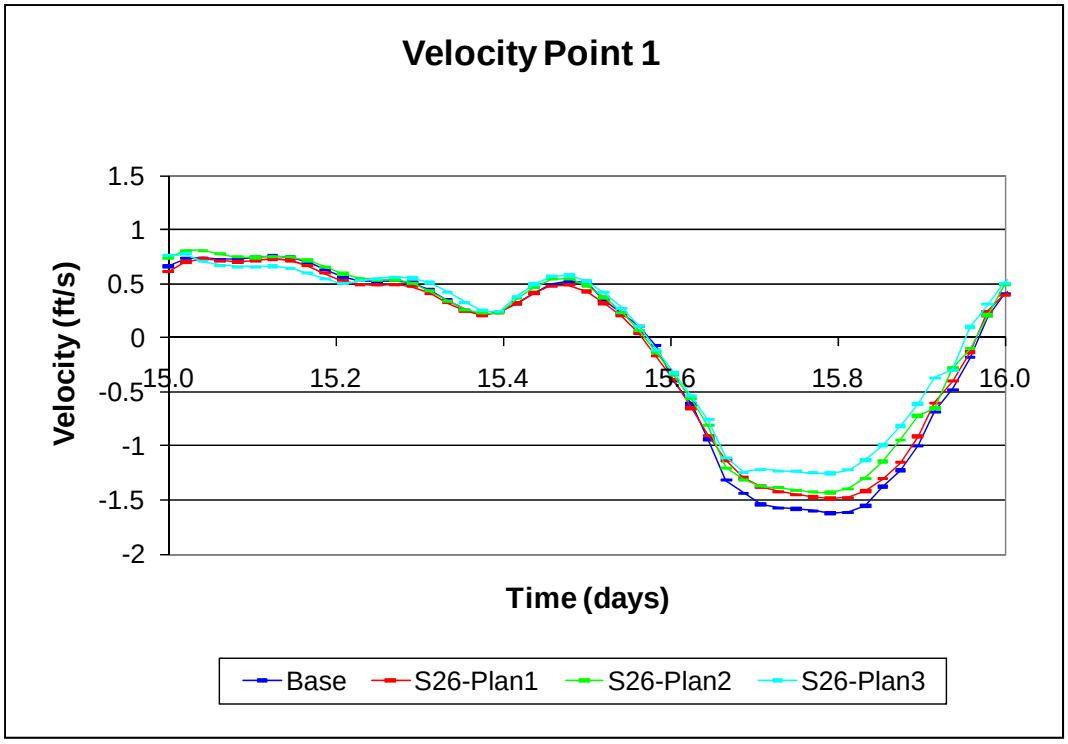

Figure 45. Velocity comparison for day 15 at point 1 for Station 26 plan set.

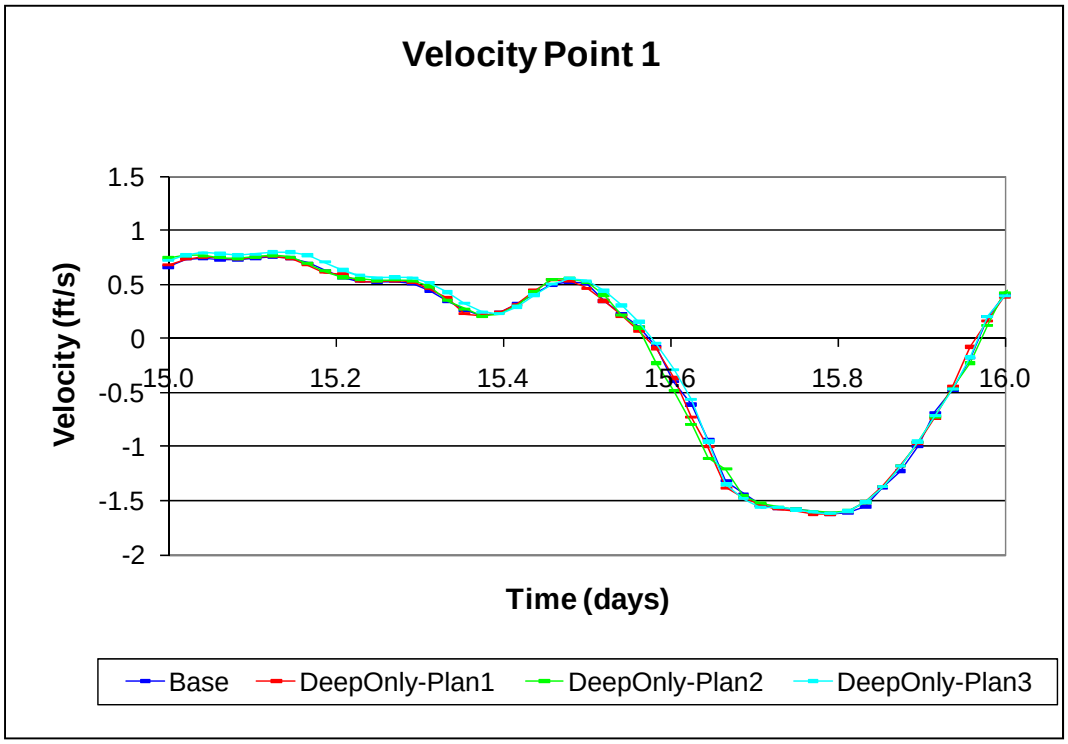

Figure 46. Velocity flux comparison for day 15 at point 1 for Deepen Only plan set.

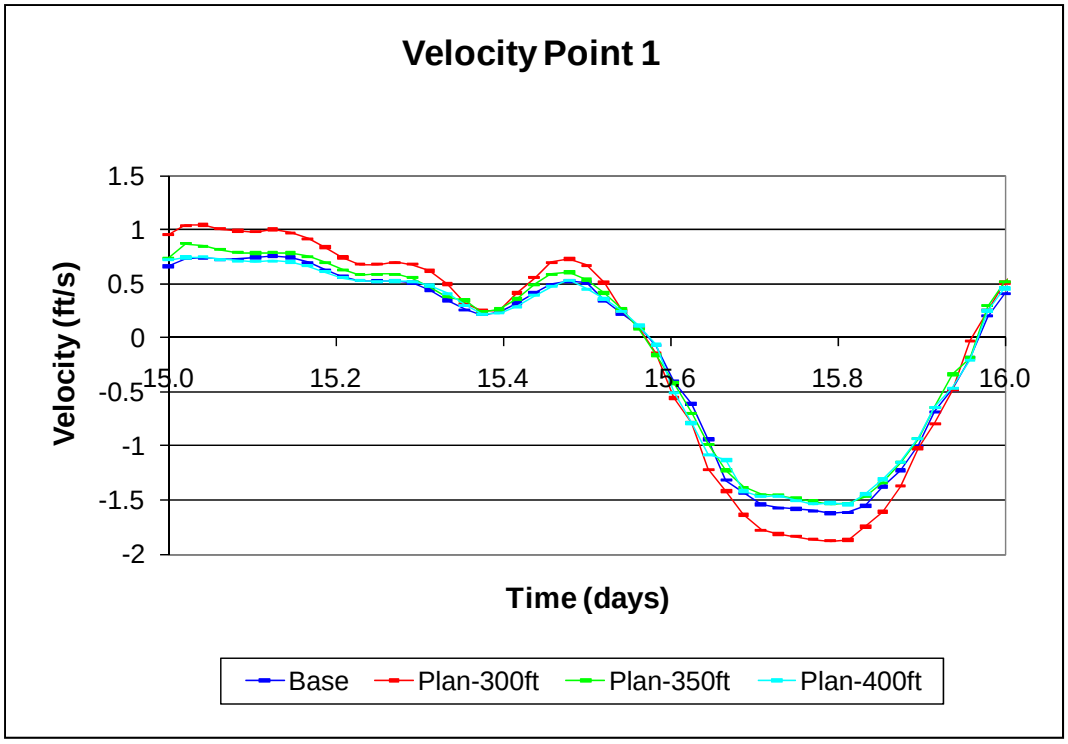

Figure 47. Velocity comparison for day 15 at point 1 for 300/350/400 plan set.

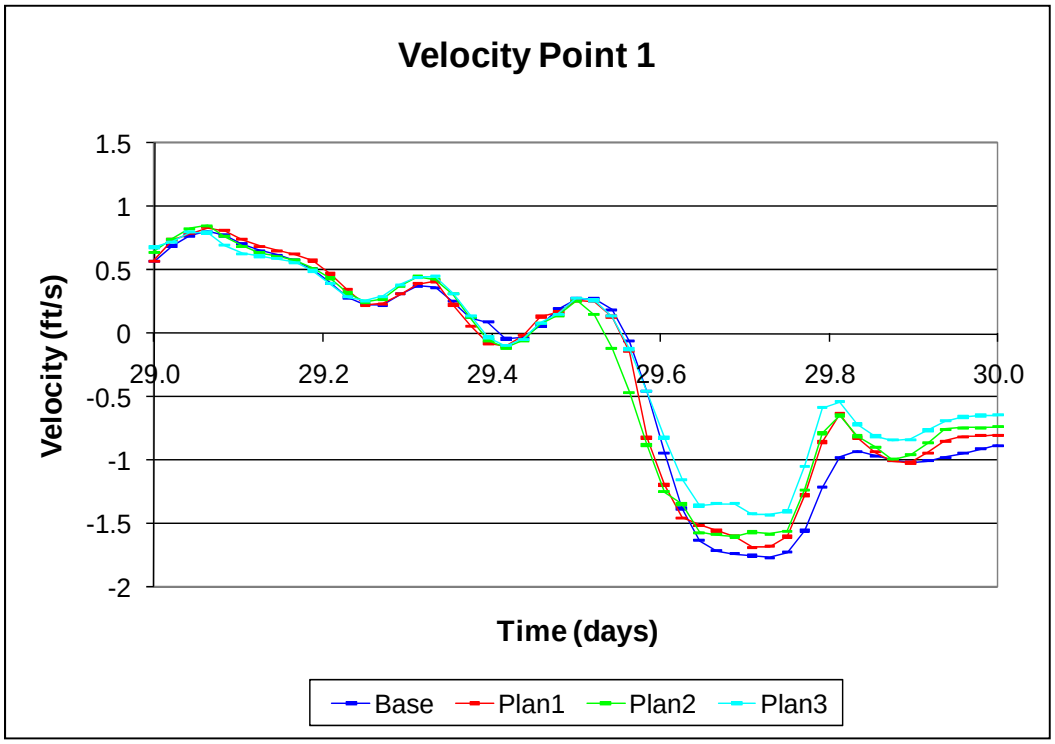

Figure 48. Velocity comparison for day 29 at point 1 for Initial plan set.

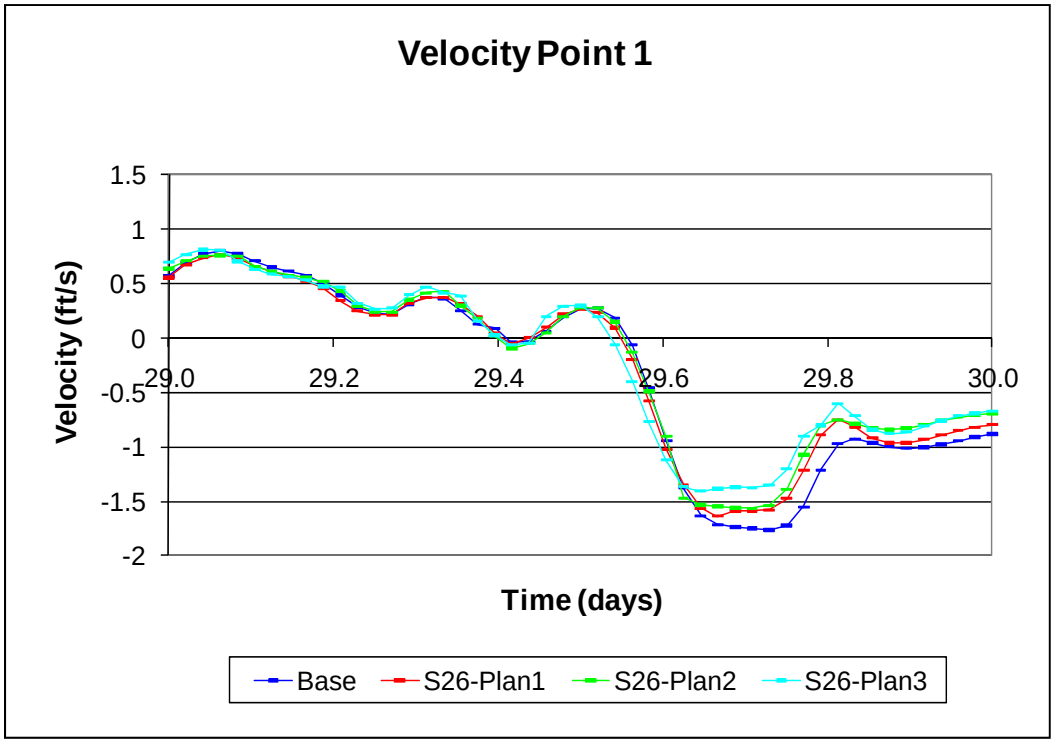

Figure 49. Velocity comparison for day 29 at point 1 for Station 26 plan set.

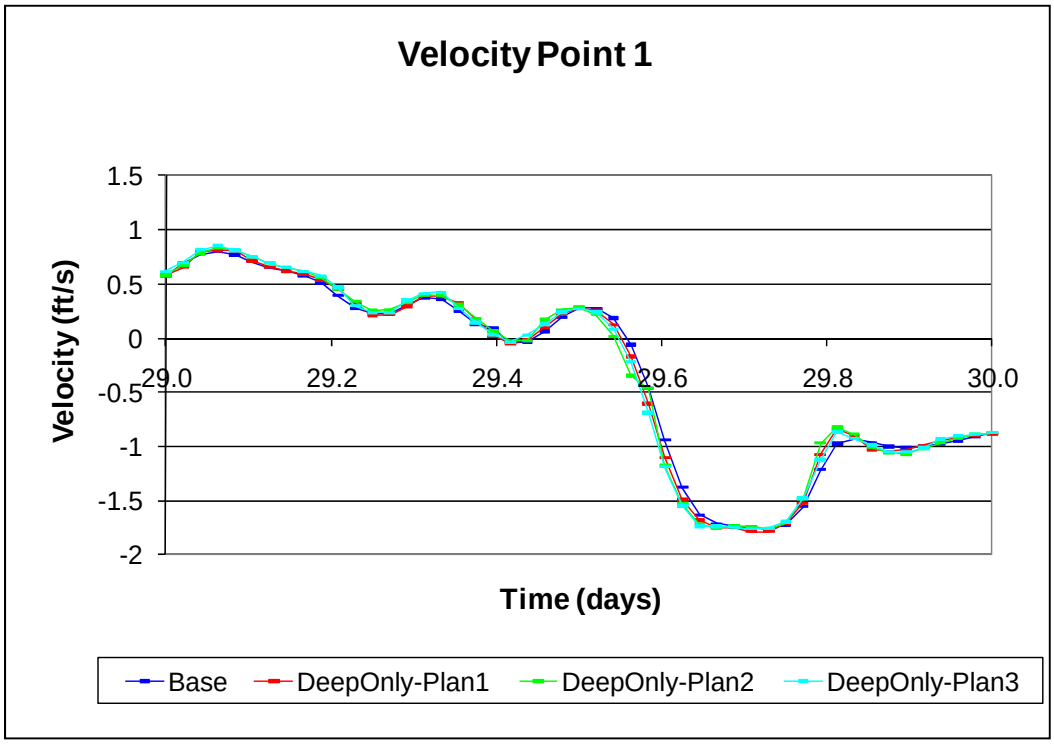

Figure 50. Velocity comparison for day 29 at point 1 for Deepen Only plan set.

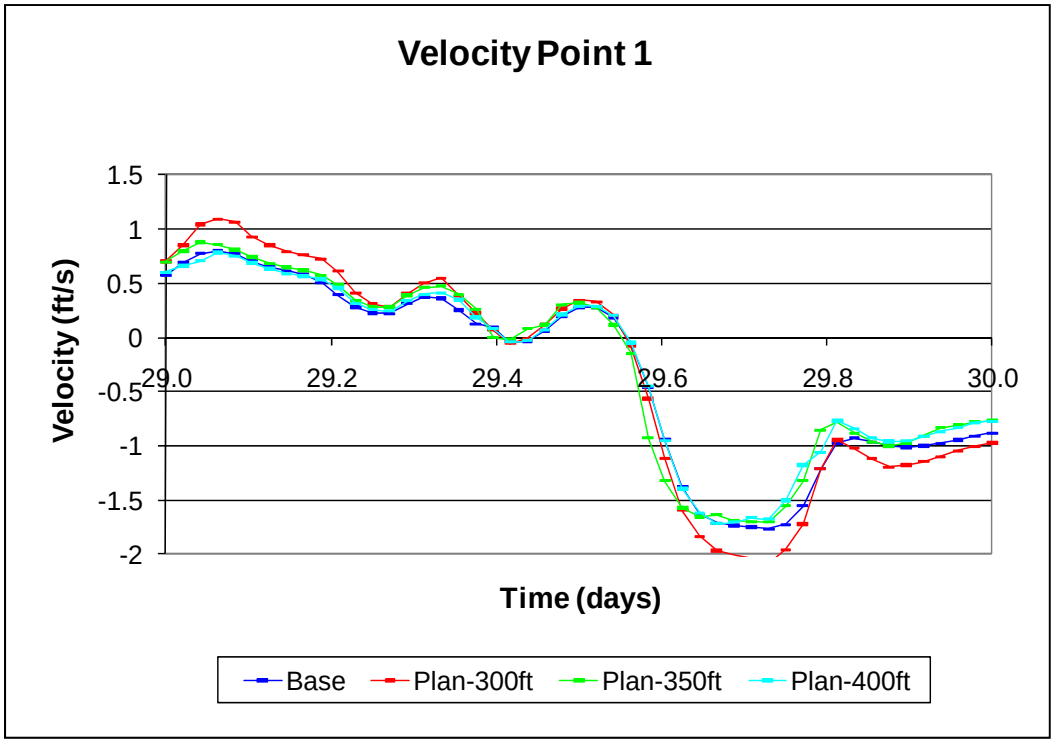

Figure 51. Velocity comparison for day 29 at point 1 for 300/350/400 plan set.

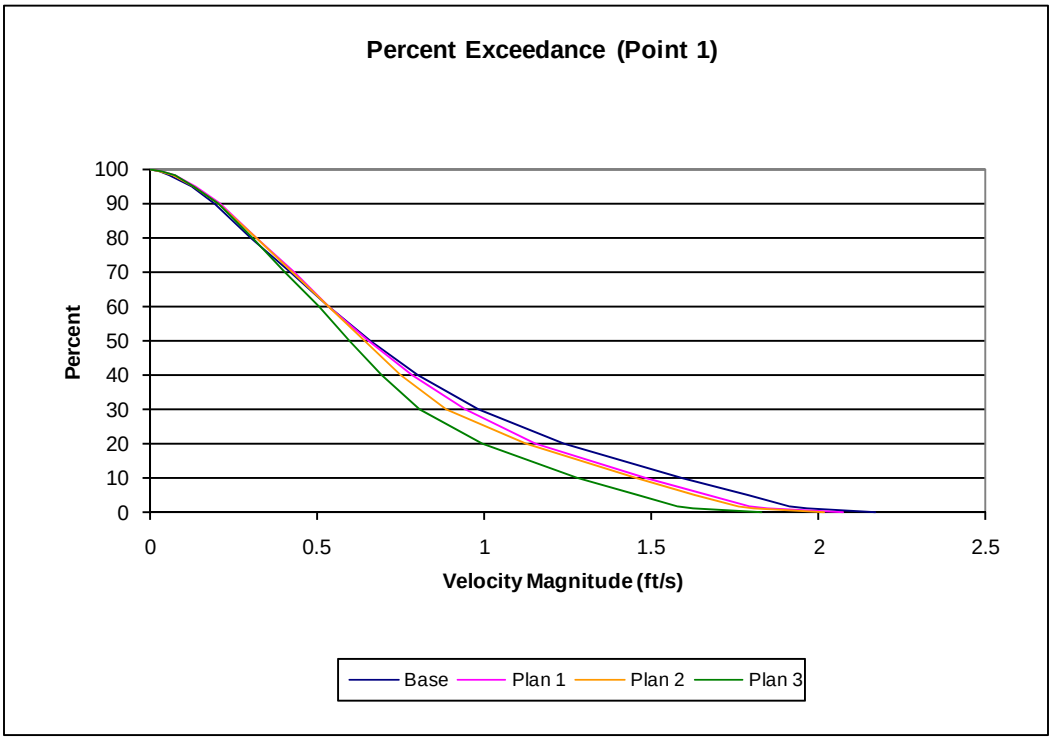

Figure 52. Percent exceedance analysis for point 1 for Initial plan set.

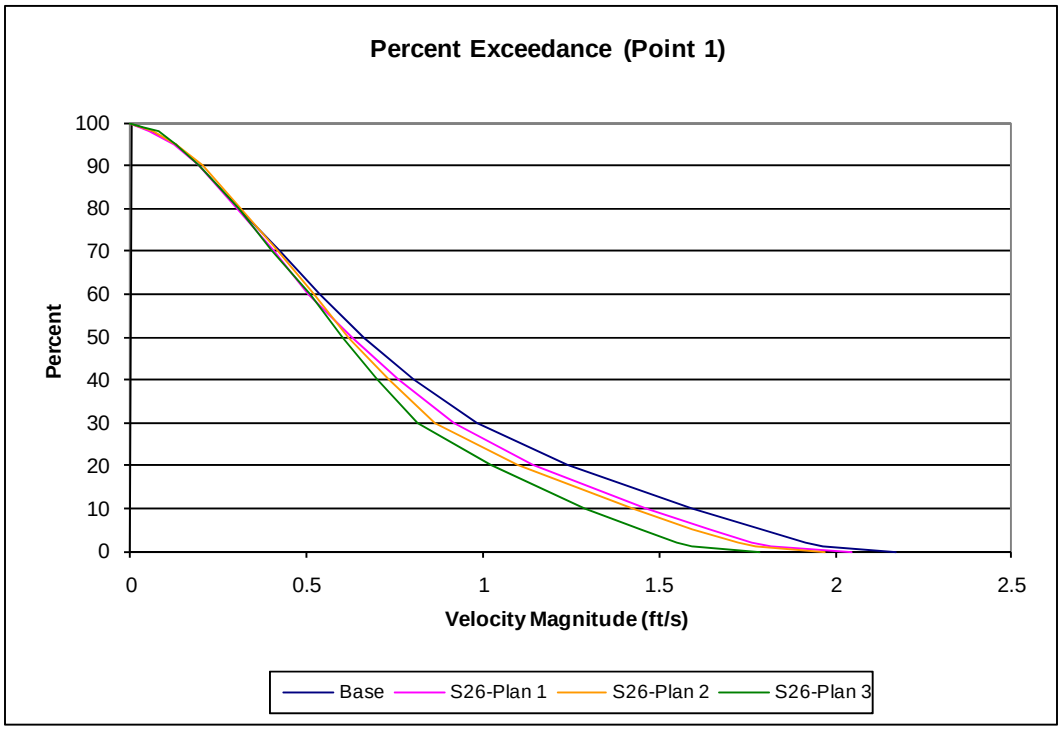

Figure 53. Percent exceedance analysis for point 1 for Station 26 plan set.

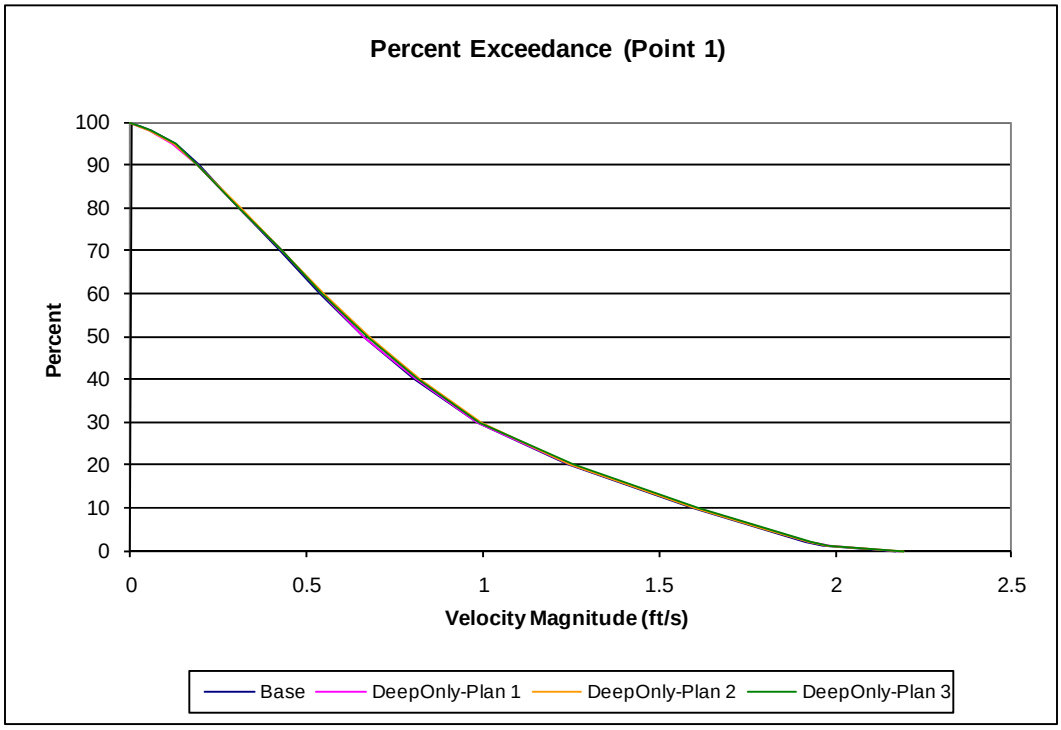

Figure 54. Percent exceedance analysis for point 1 for Deepen Only plan set.

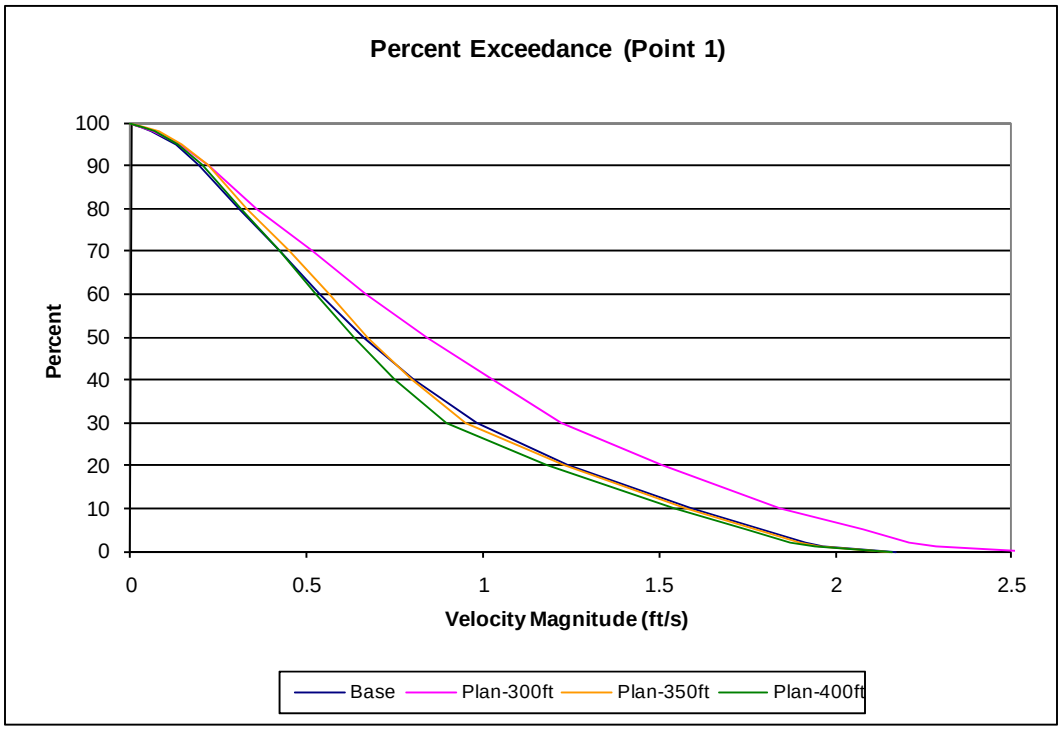

Figure 55. Percent exceedance analysis for point 1 for 300/350/400 plan set.

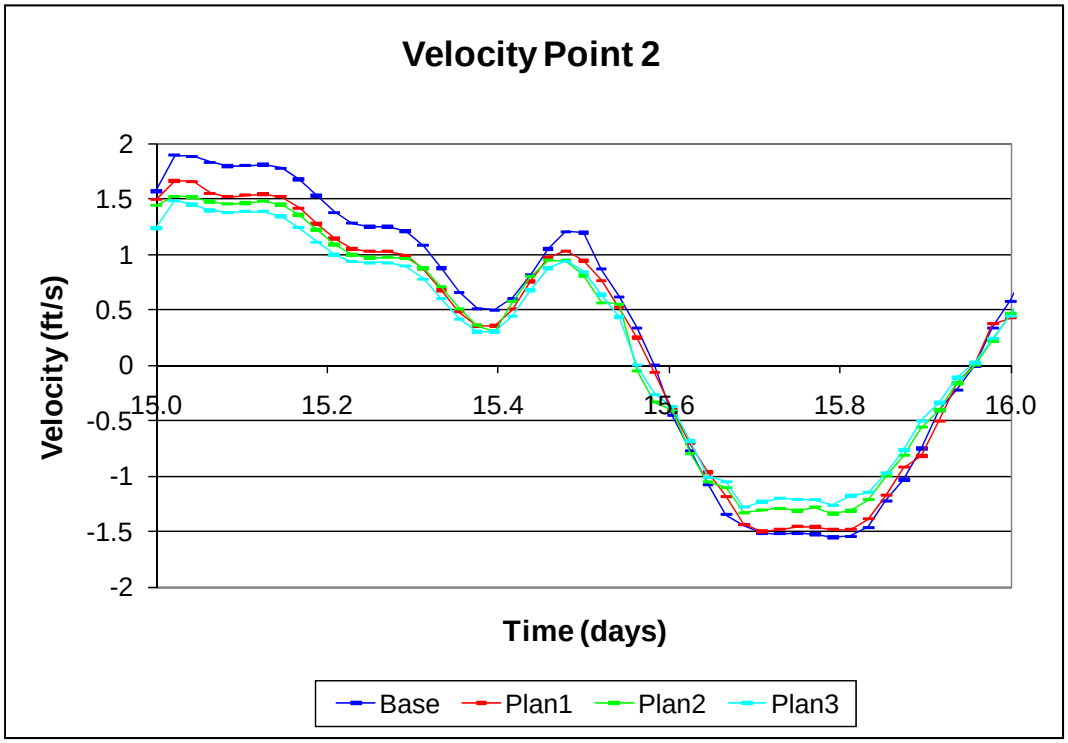

Figure 60. Velocity comparison for day 15 at point 2 for Initial plan set.

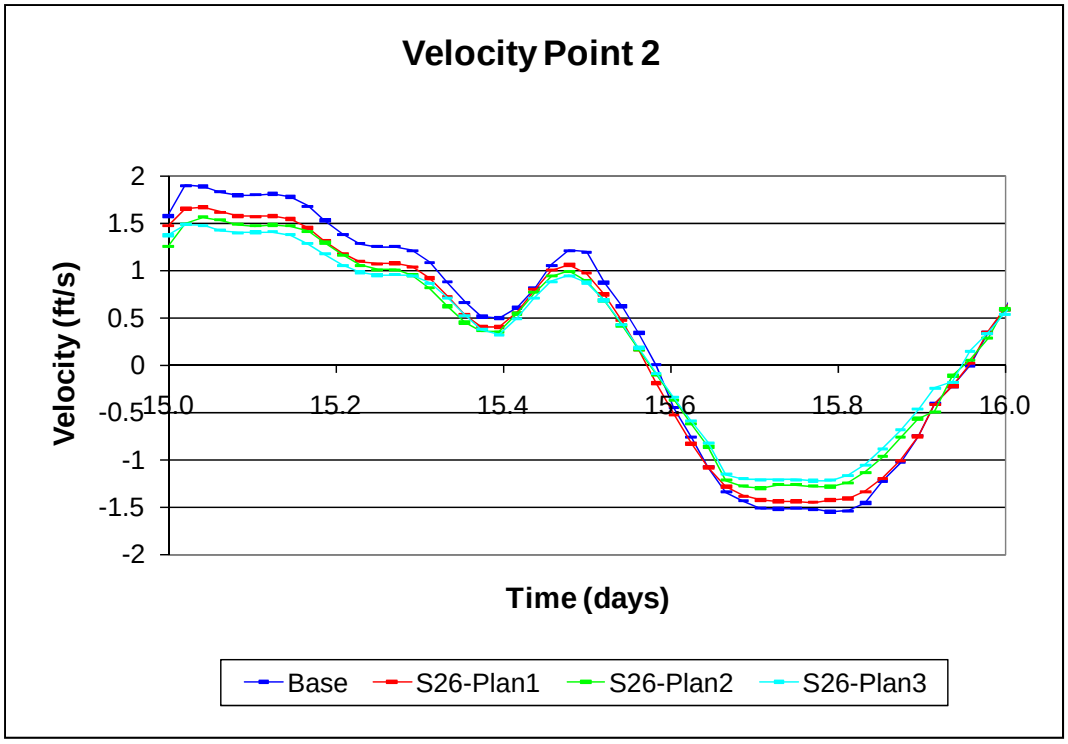

Figure 61. Velocity comparison for day 15 at point 2 for Station 26 plan set.

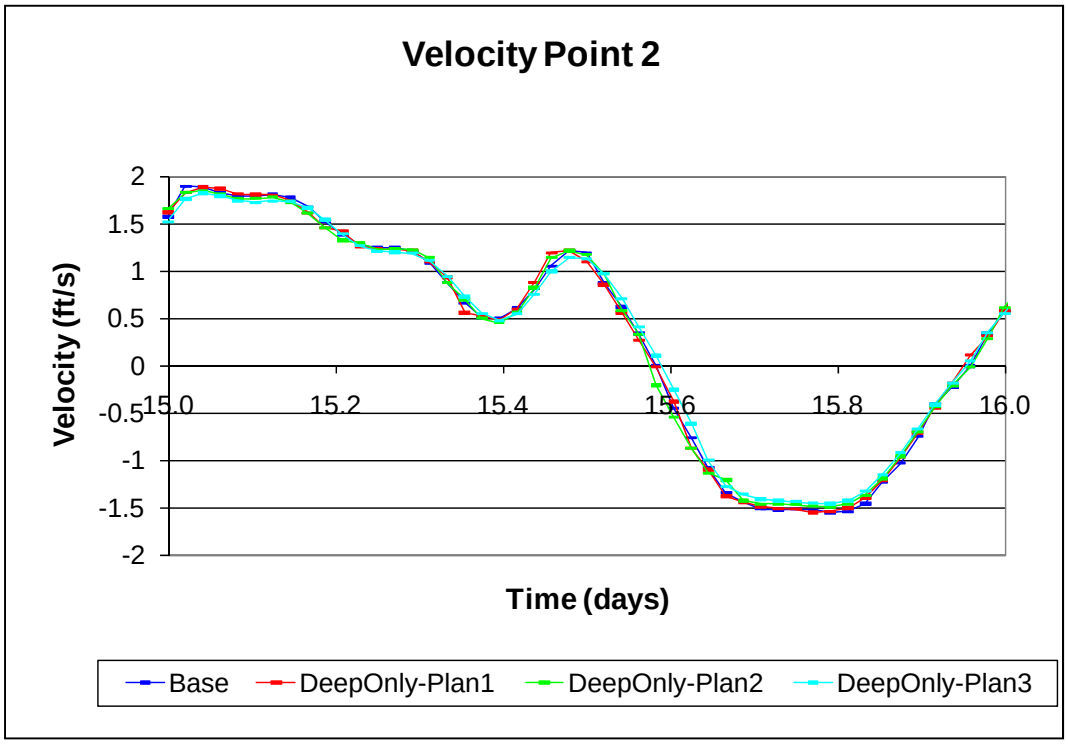

Figure 62. Velocity comparison for day 15 at point 2 for Deepen Only plan set.

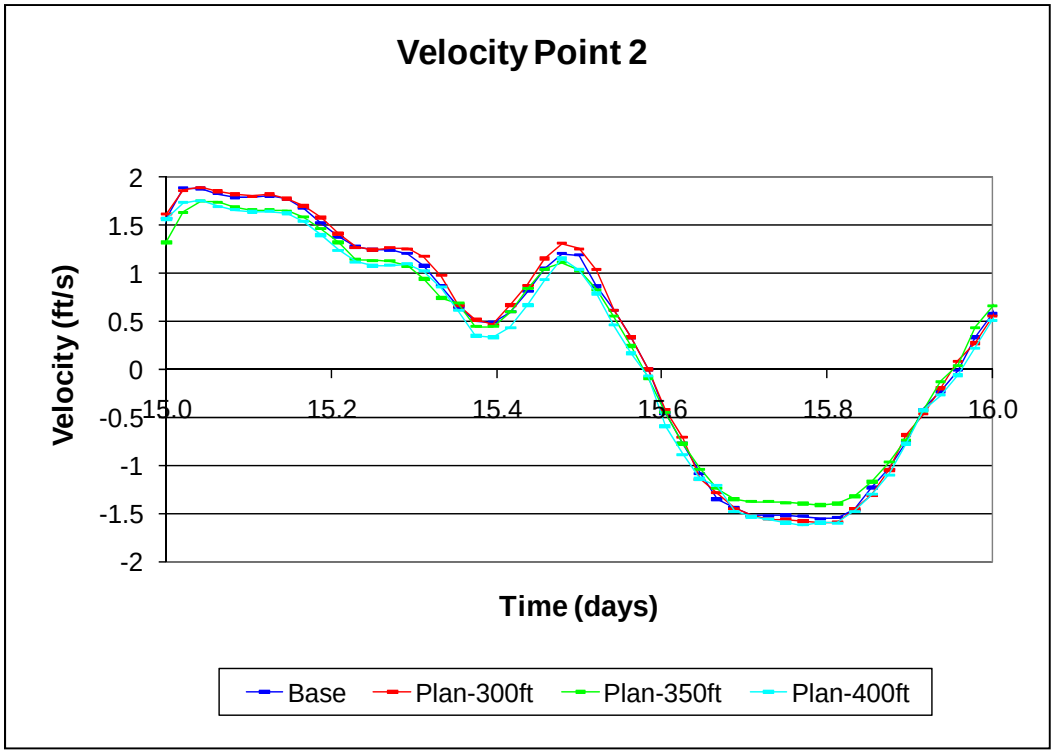

Figure 56. Velocity comparison for day 15 at point 2 for 300/350/400 plan set.

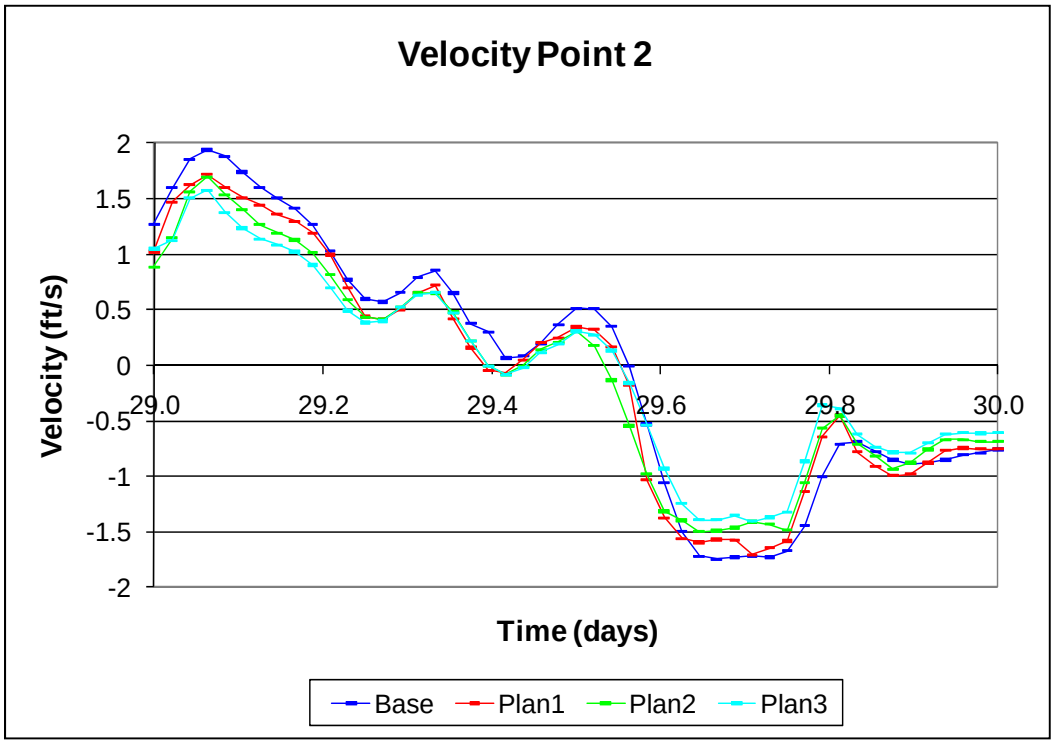

Figure 57. Velocity comparison for day 29 at point 2 for Initial plan set.

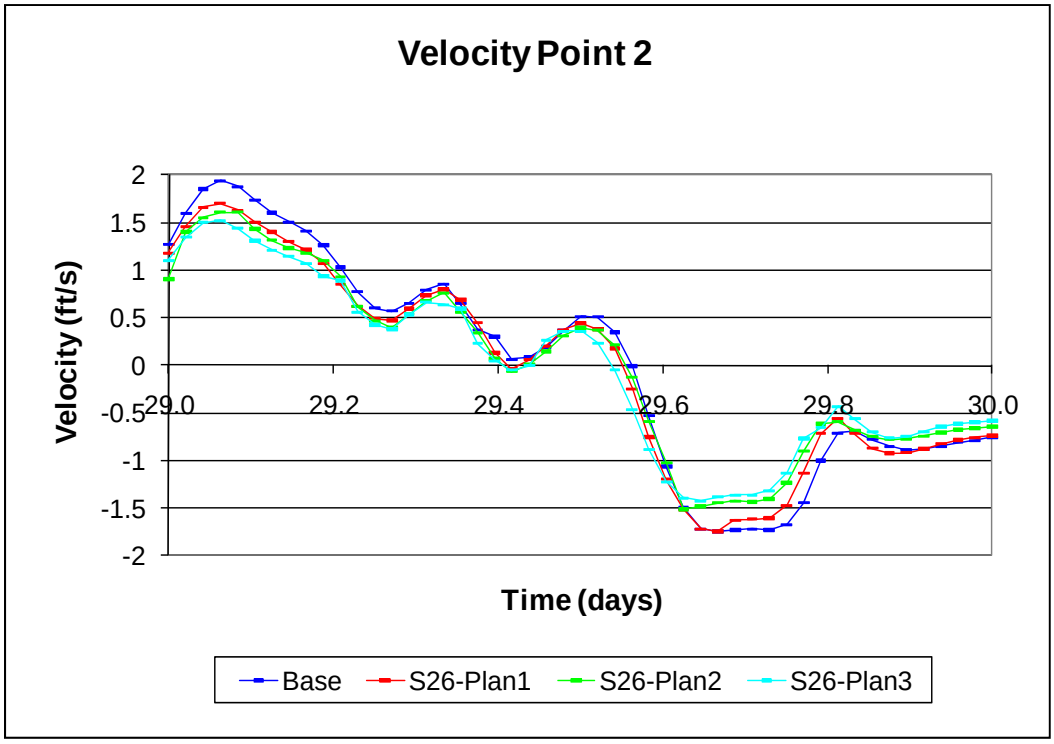

Figure 65. Velocity comparison for day 29 at point 2 for Station 26 plan set.

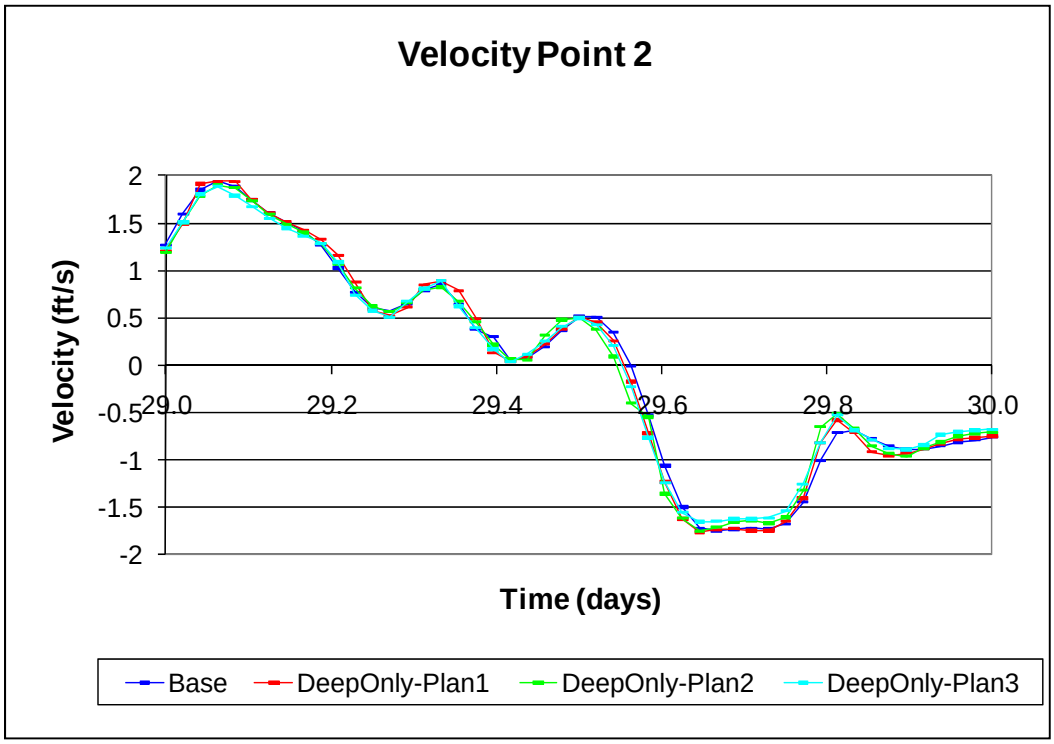

Figure 58. Velocity comparison for day 29 at point 2 Deepen Only plan set.

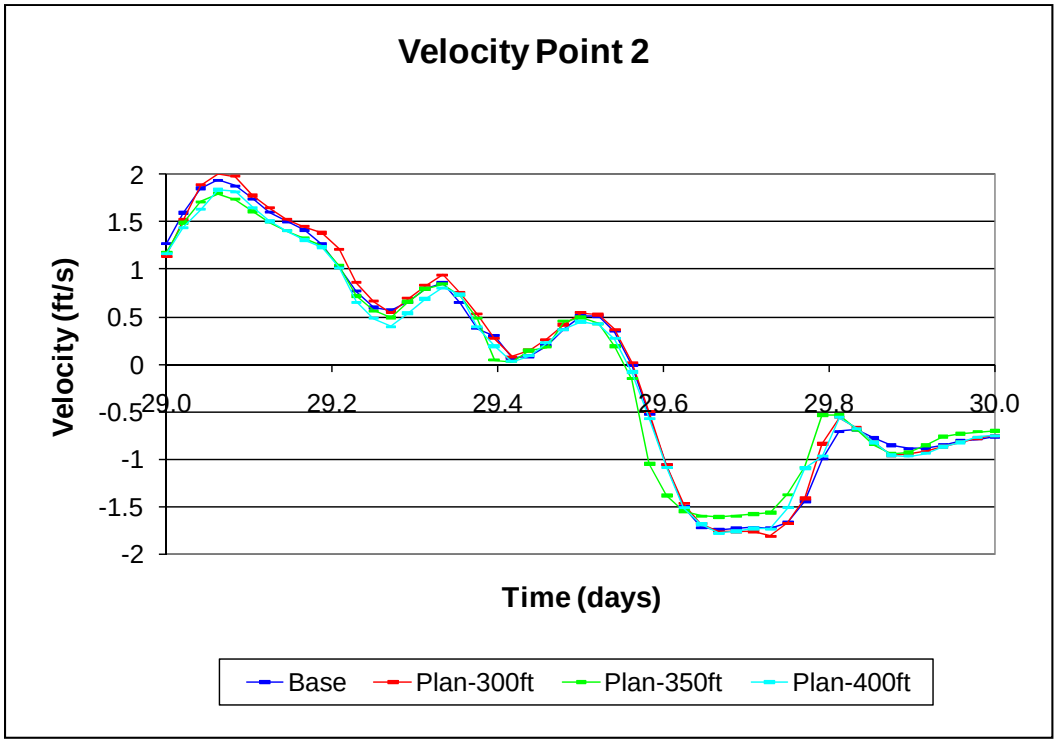

Figure 59. Velocity comparison for day 29 at point 2 for 300/350/400 plan set.

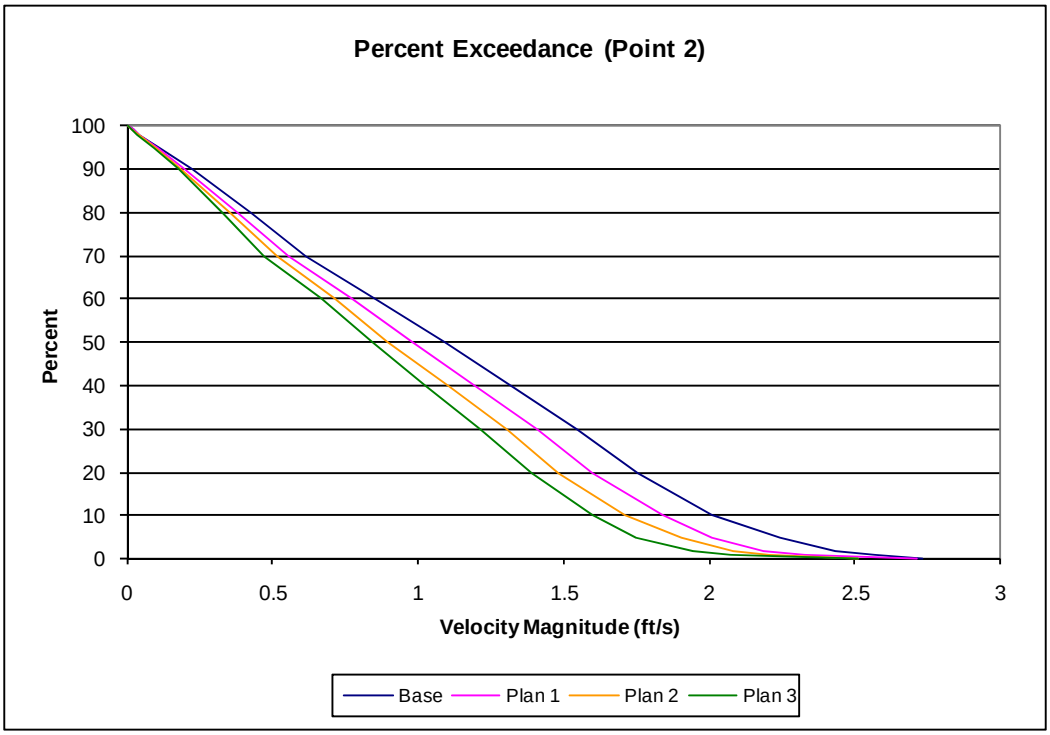

Figure 60. Percent exceedance analysis for point 2 for Initial plan set.

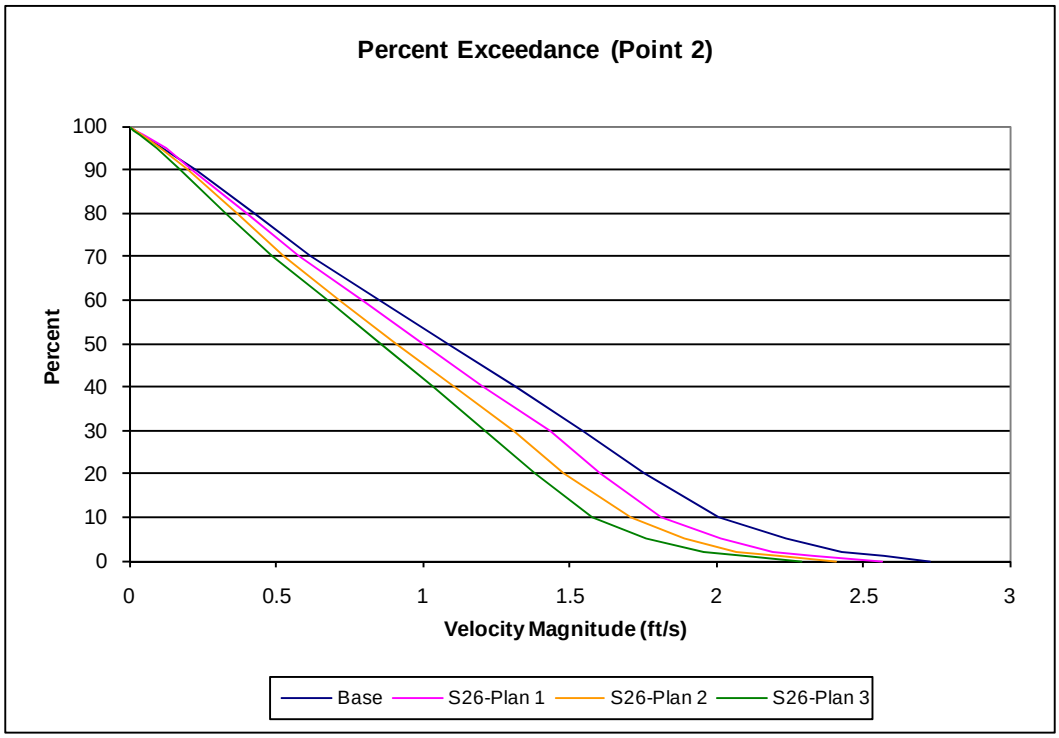

Figure 61. Percent exceedance analysis for point 2 for Station 26 plan set.

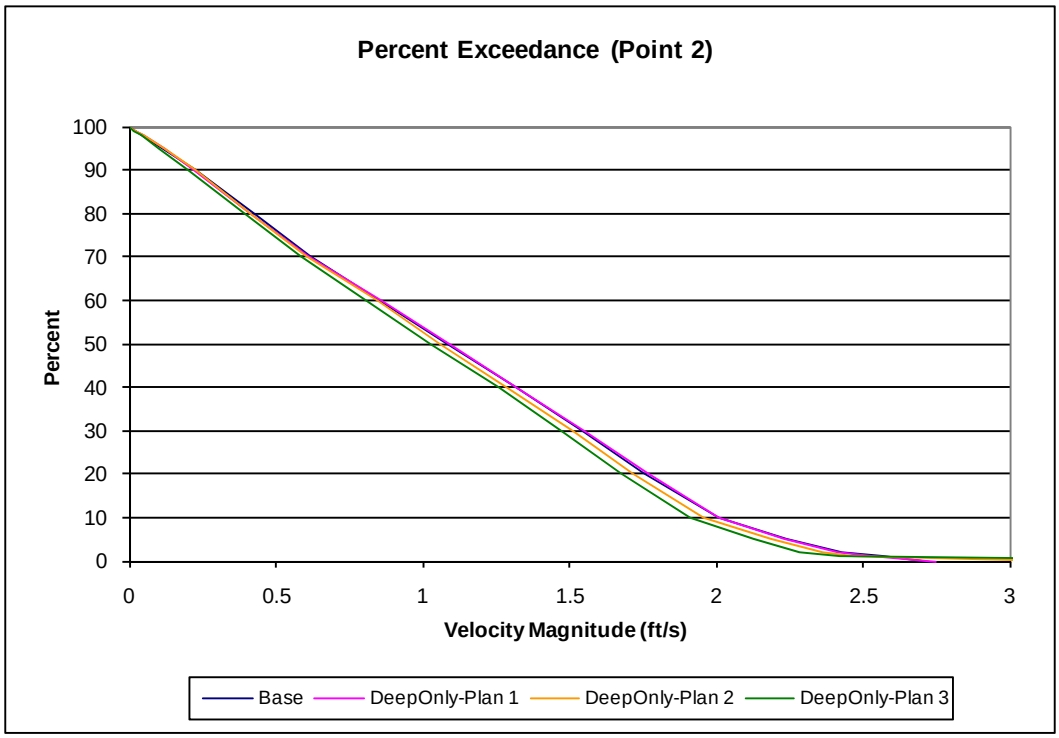

Figure 62. Percent exceedance analysis for point 2 for Deepen Only plan set.

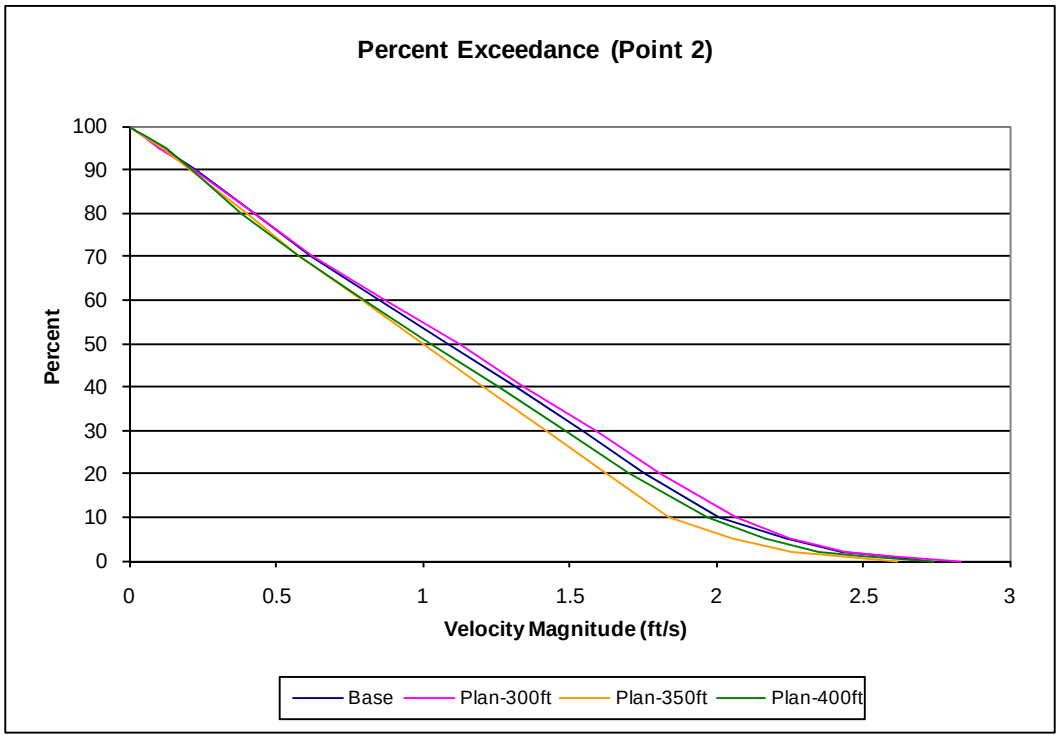

Figure 63. Percent exceedance analysis for point 2 for 300/350/400 plan set.

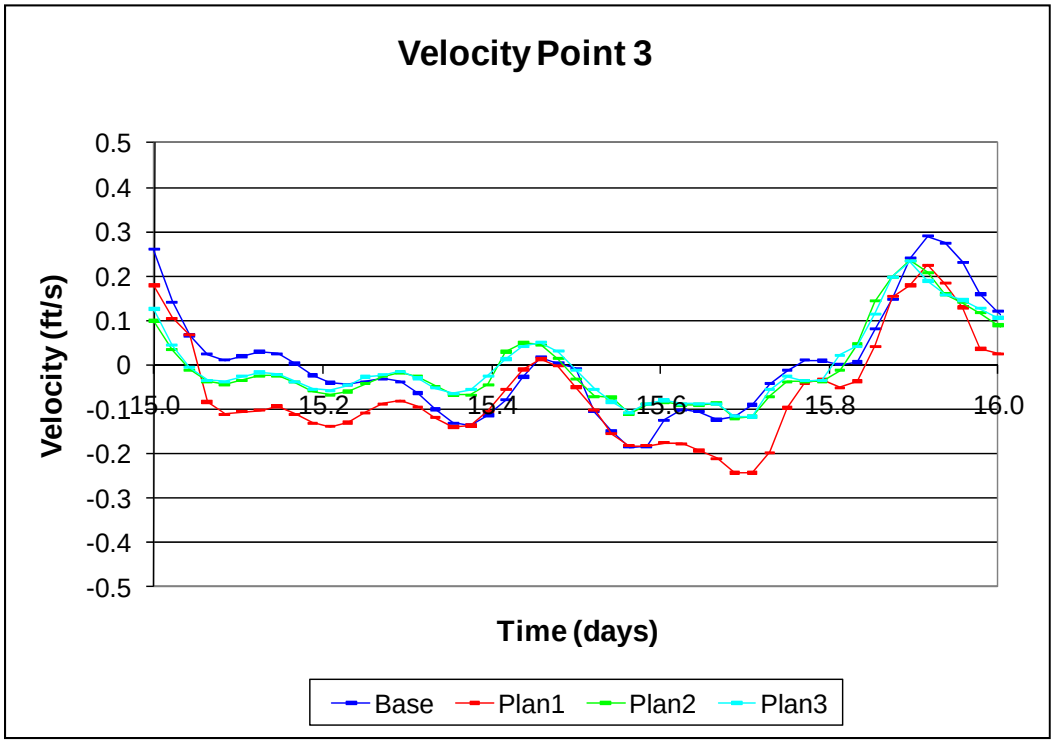

Figure 64. Velocity comparison for day 15 at point 3 for Initial plan set.

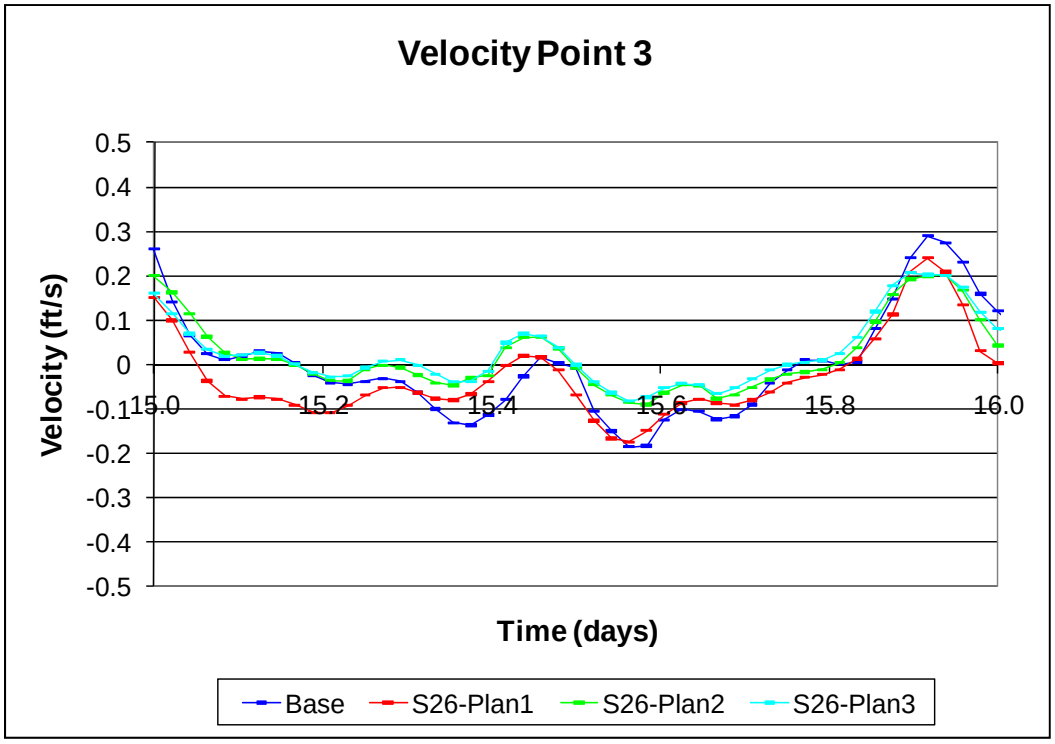

Figure 65. Velocity comparison for day 15 at point 3 for Station 26 plan set.

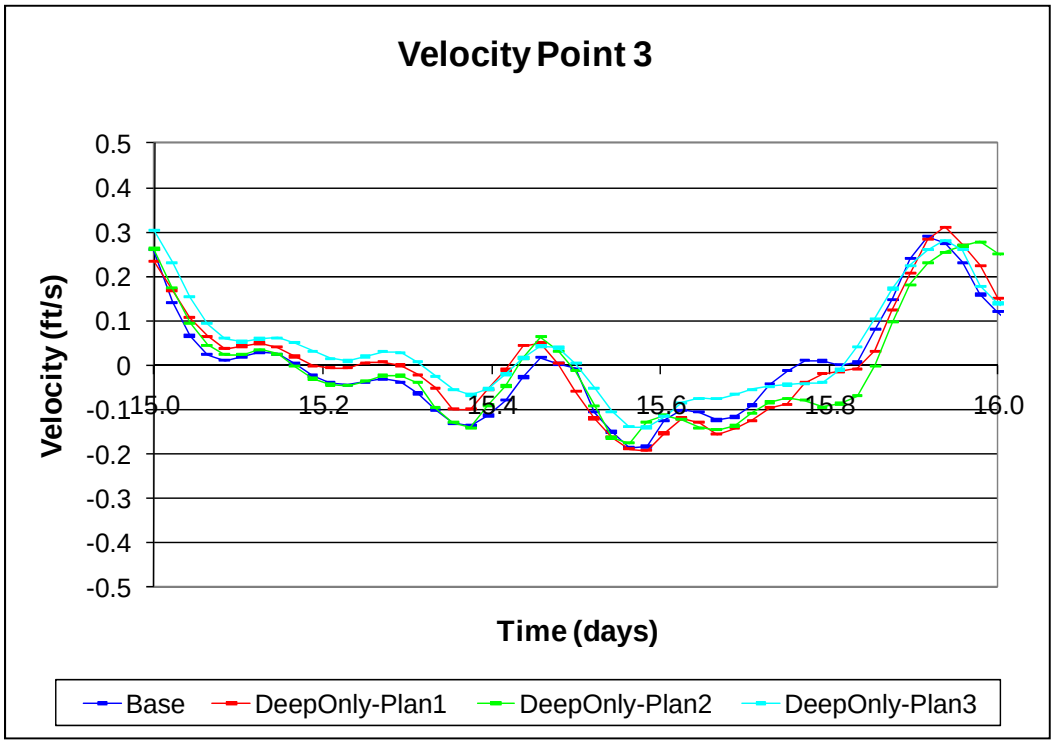

Figure 66. Velocity comparison for day 15 at point 3 for Deepen Only plan set.

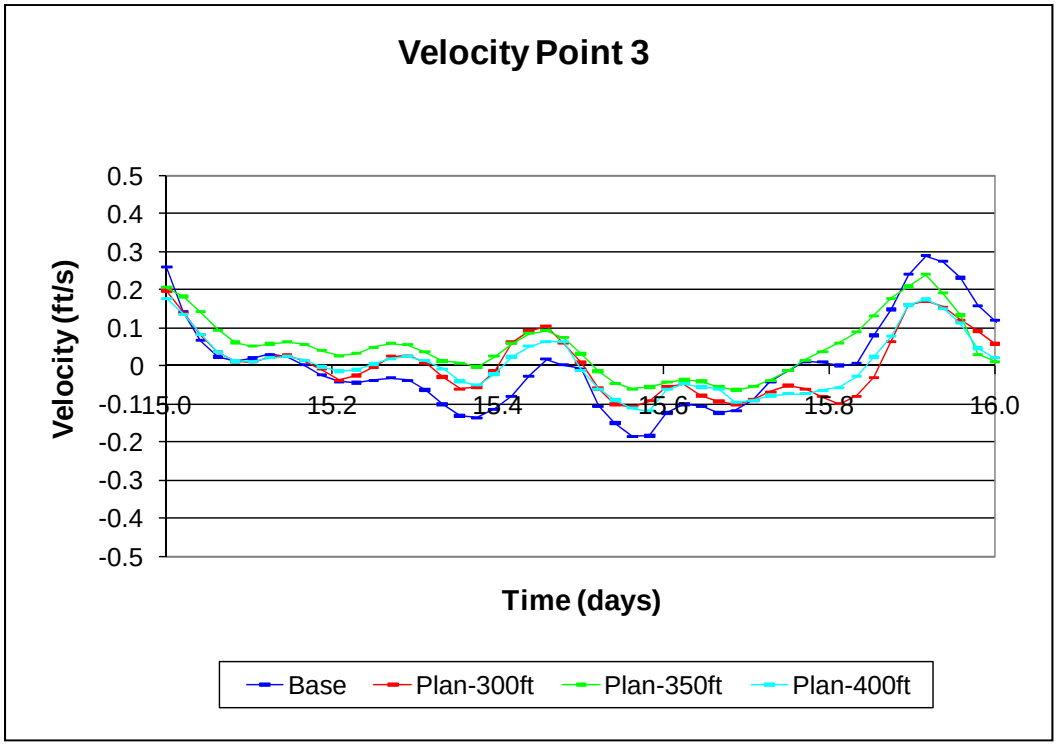

Figure 67. Velocity comparison for day 15 at point 3 for 300/350/400 plan set.

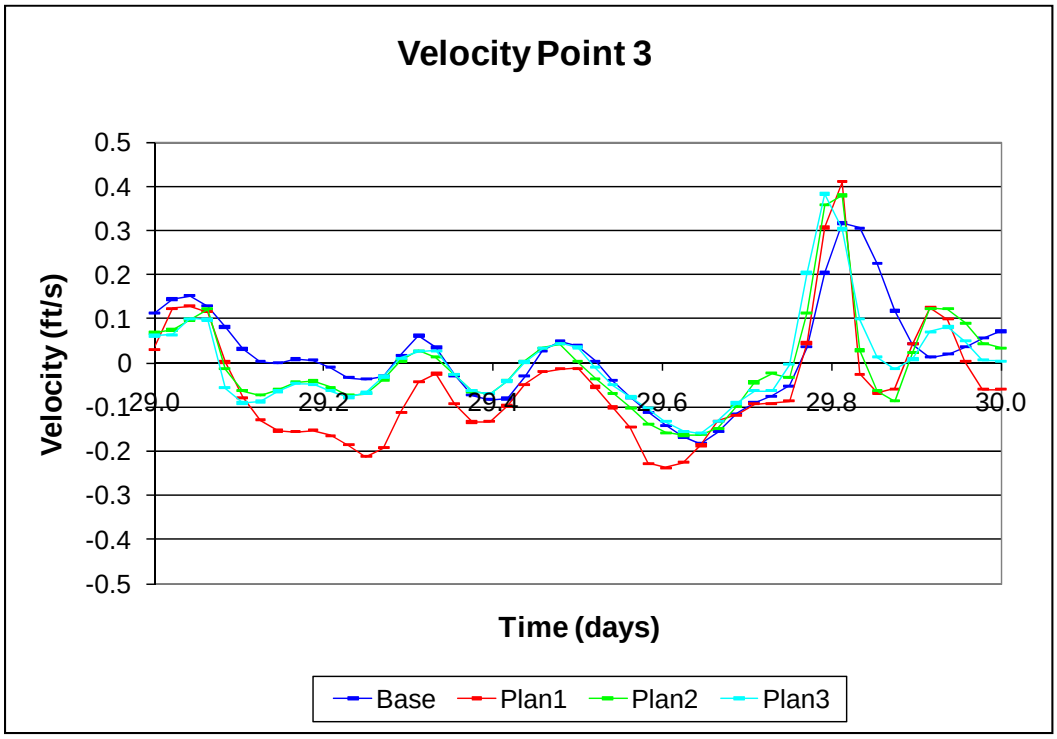

Figure 68. Velocity comparison for day 29 at point 3 for Initial plan set.

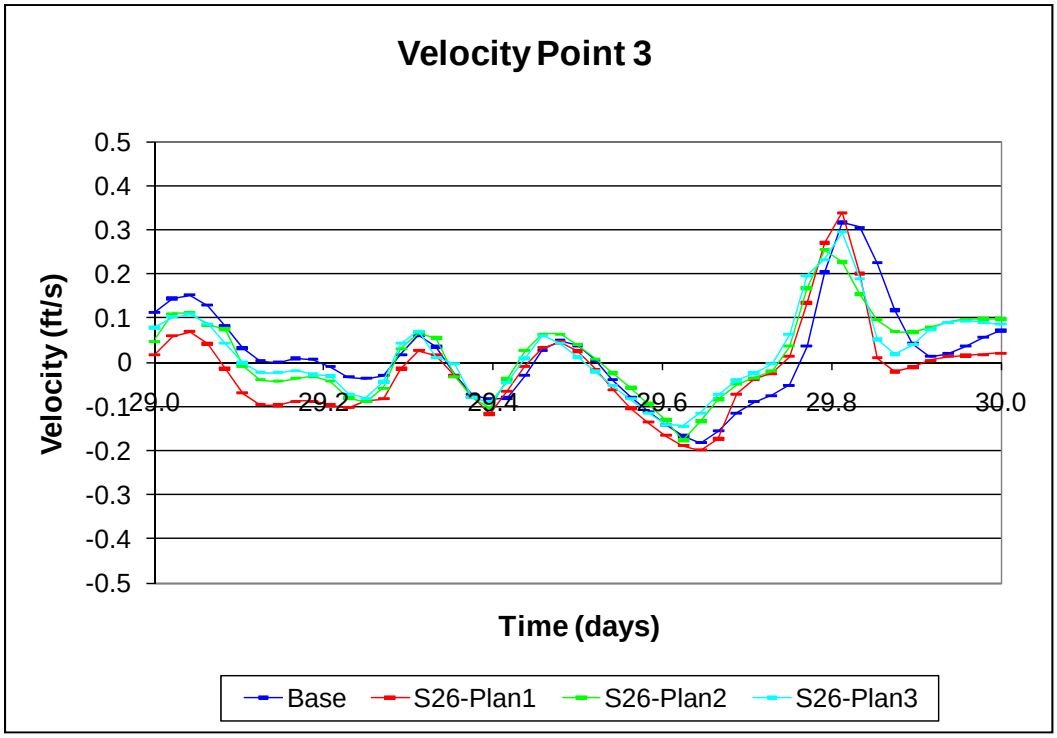

Figure 69. Velocity comparison for day 29 at point 3 for Station 26 plan set.

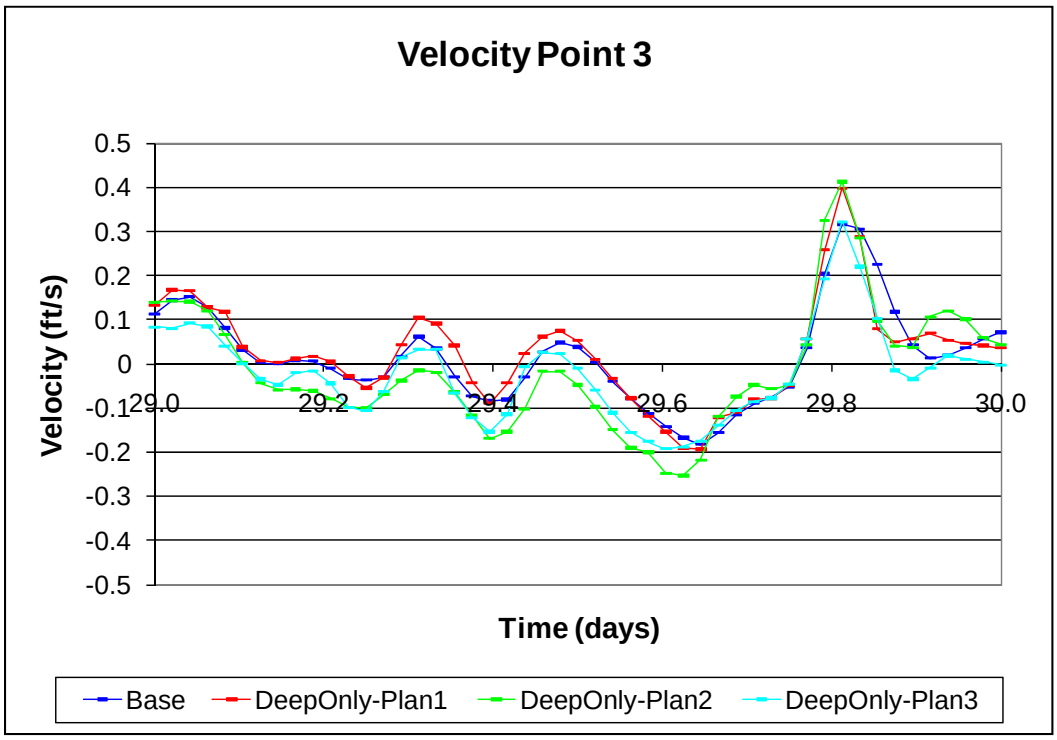

Figure 70. Velocity comparison for day 29 at point 3 for Deepen Only plan set.

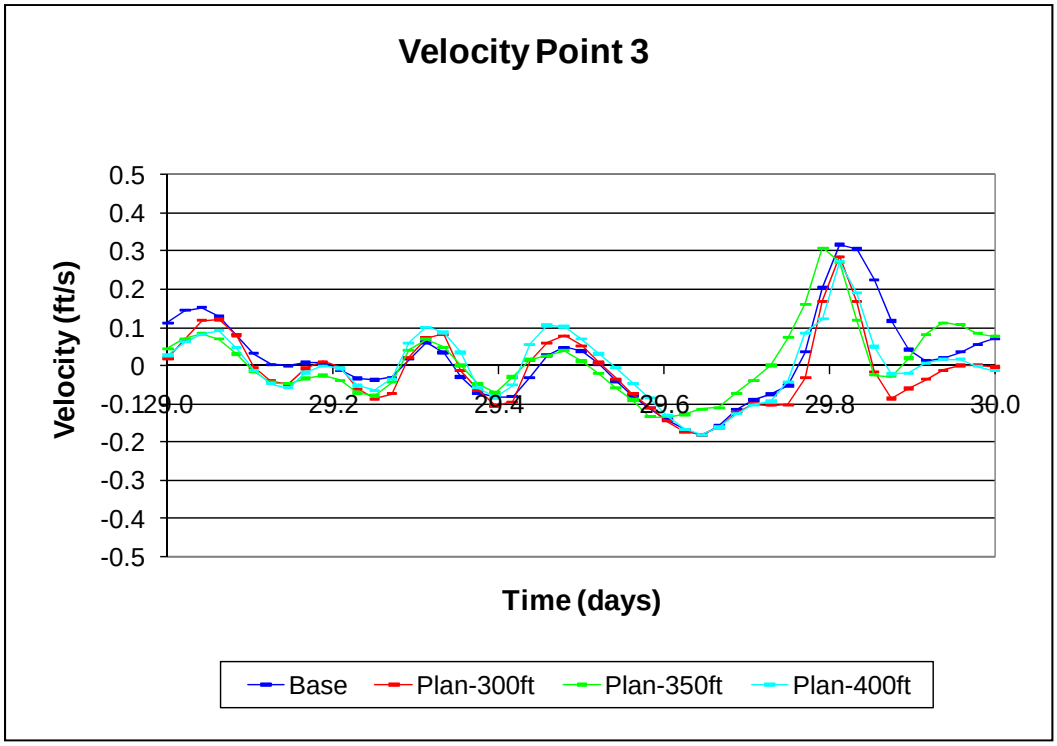

Figure 71. Velocity comparison for day 29 at point 3 for 300/350/400 plan set.

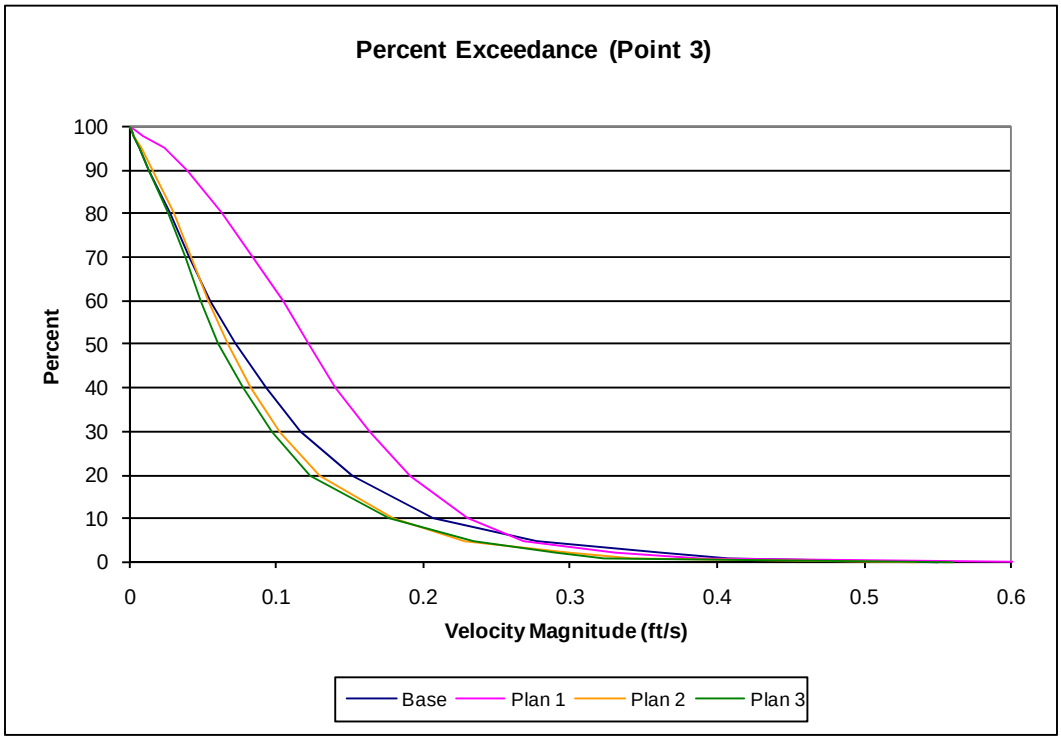

Figure 72. Percent exceedance analysis for point 3 for Initial plan set.

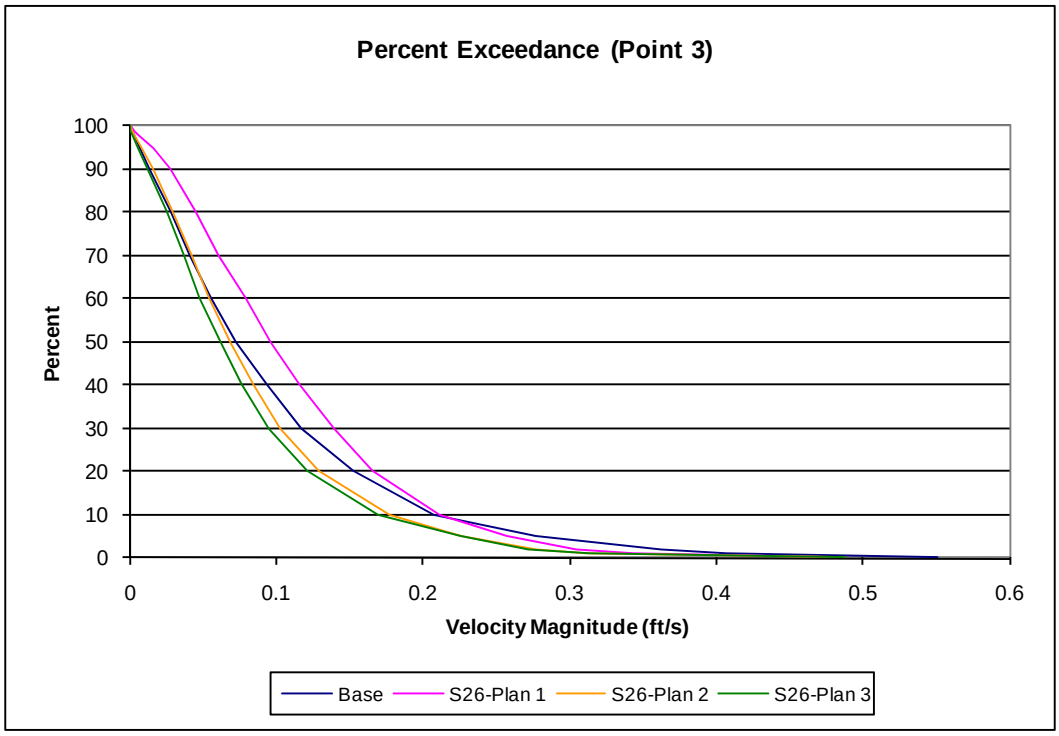

Figure 73. Percent exceedance analysis for point 3 for Station 26 plan set.

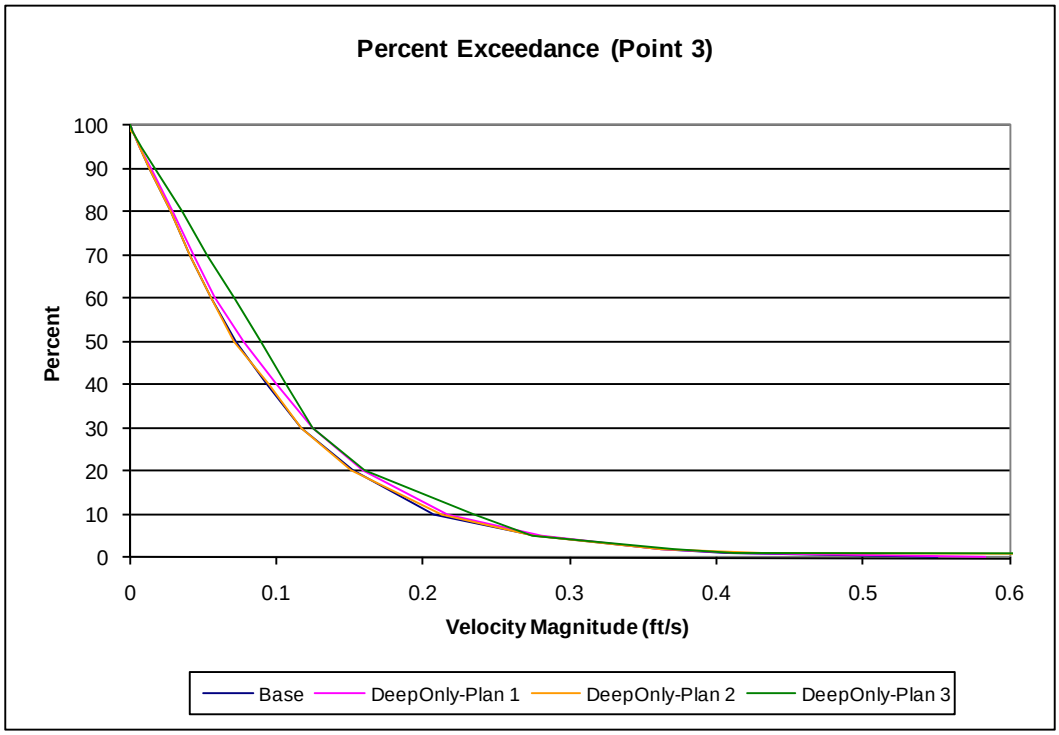

Figure 74. Percent exceedance analysis for point 3 for Deepen Only plan set.

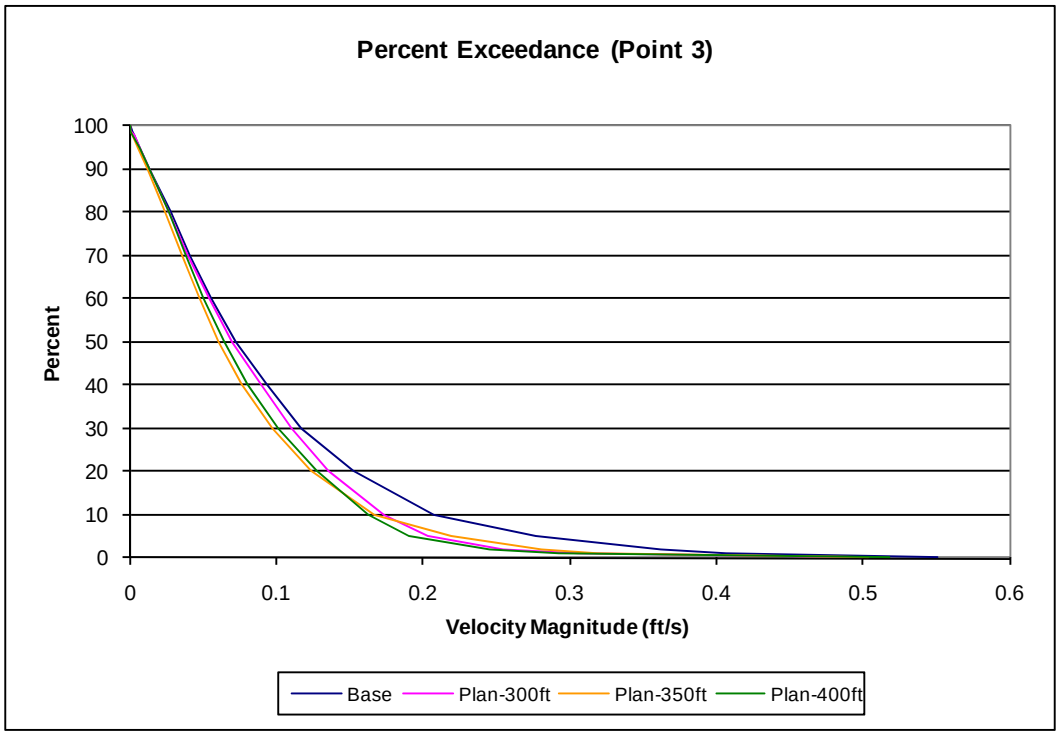

Figure 75. Percent exceedance analysis for point 3 for 300/350/400 plan set.

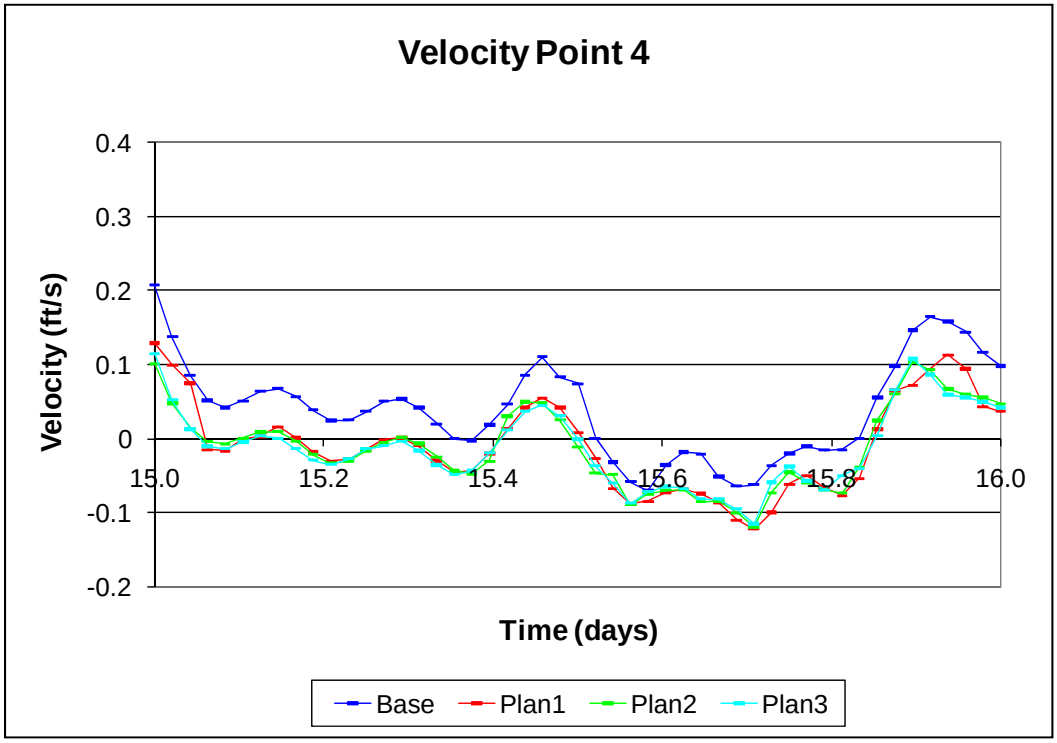

Figure 76. Velocity comparison for day 15 at point 4 for Initial plan set.

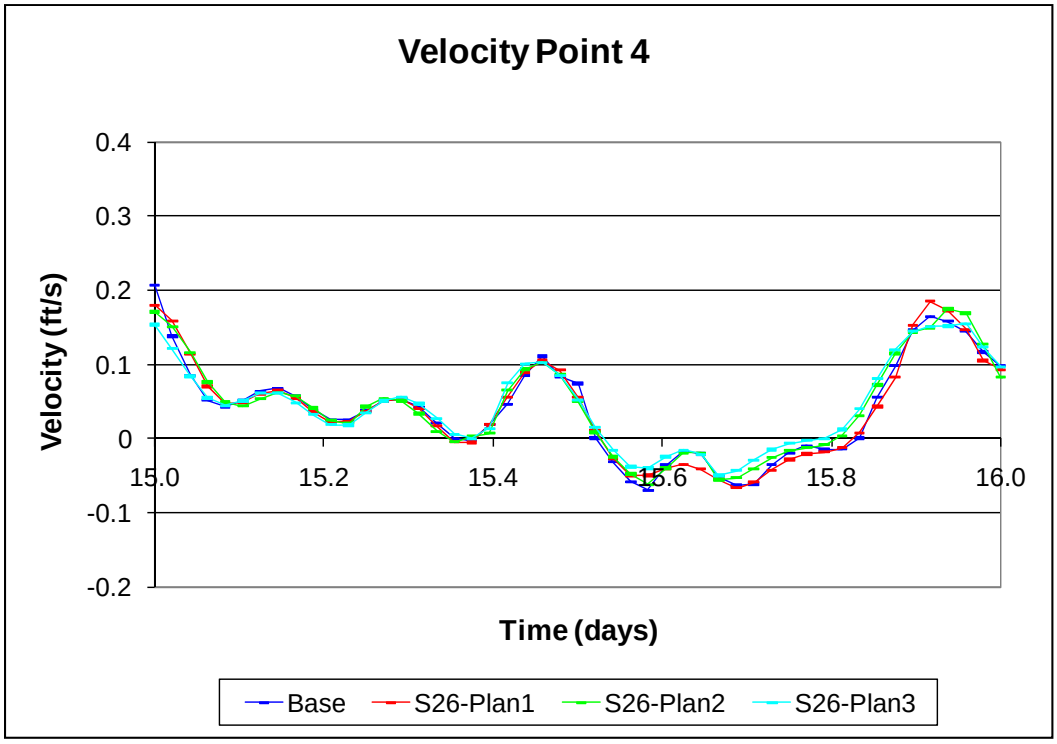

Figure 77. Velocity comparison for day 15 at point 4 for Station 26 plan set.

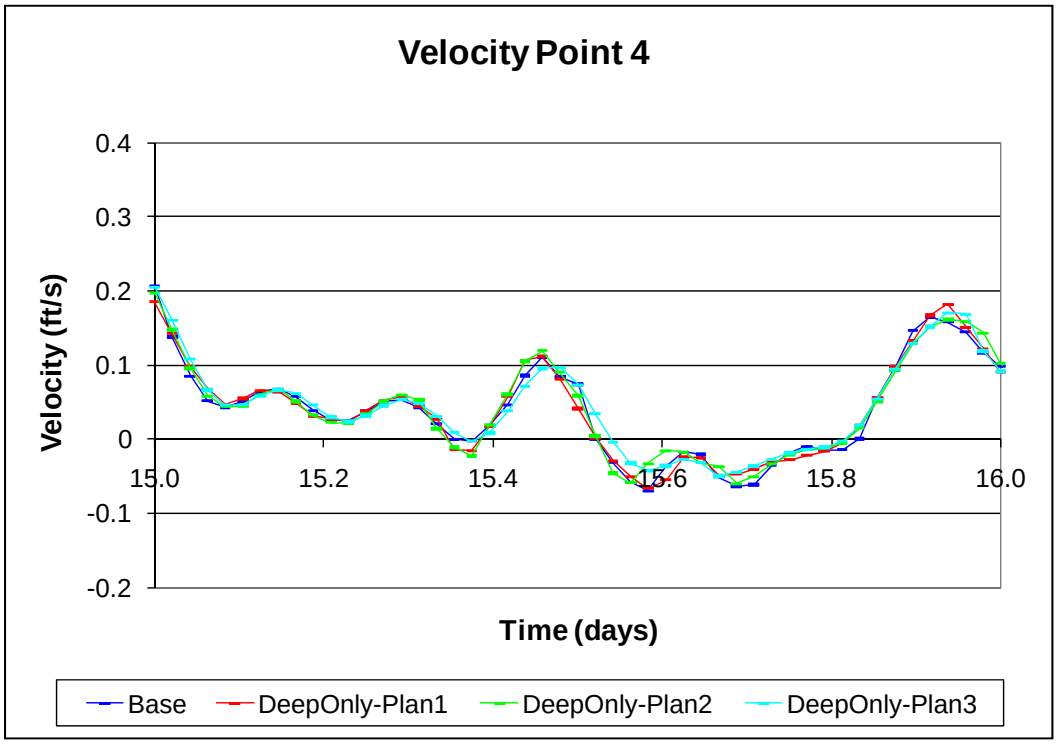

Figure 78. Velocity comparison for day 15 at point 4 for Deepen Only plan set.

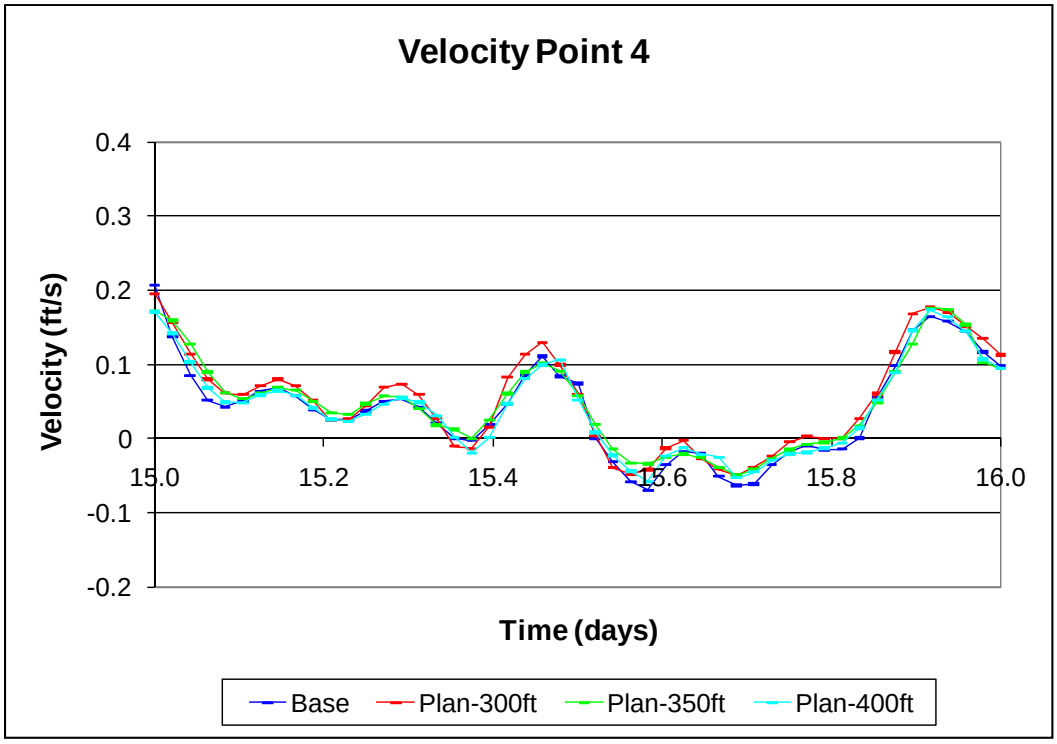

Figure 79. Velocity comparison for day 15 at point 4 for 300/350/400 plan set.

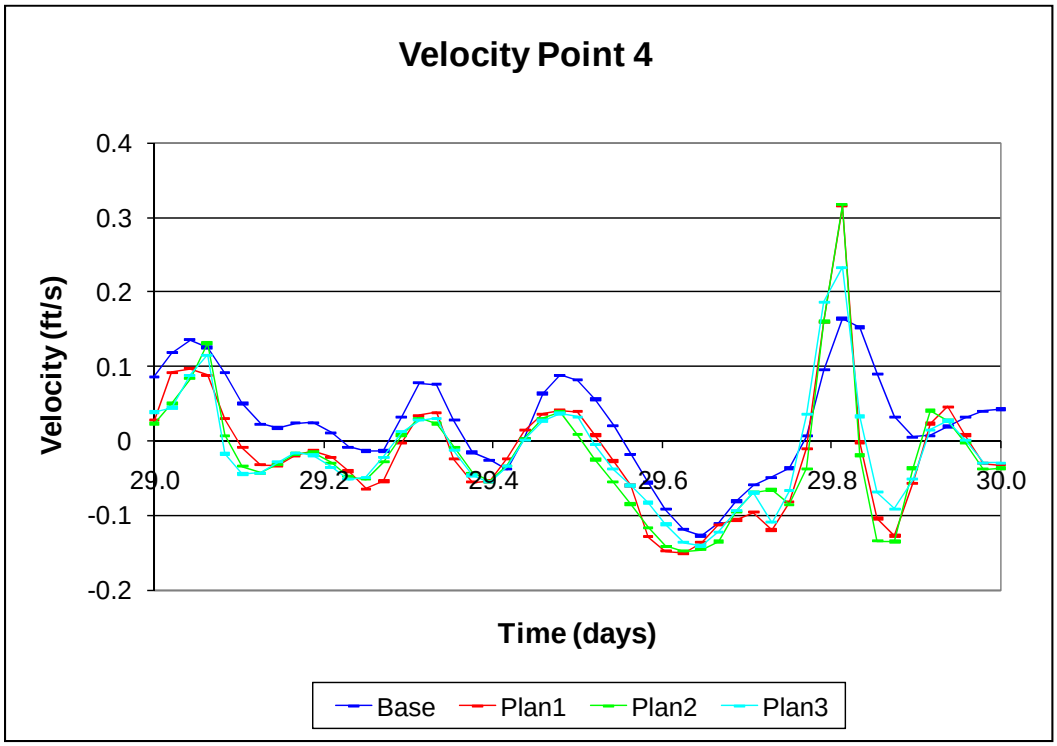

Figure 80. Velocity comparison for day 29 at point 4 for Initial plan set.

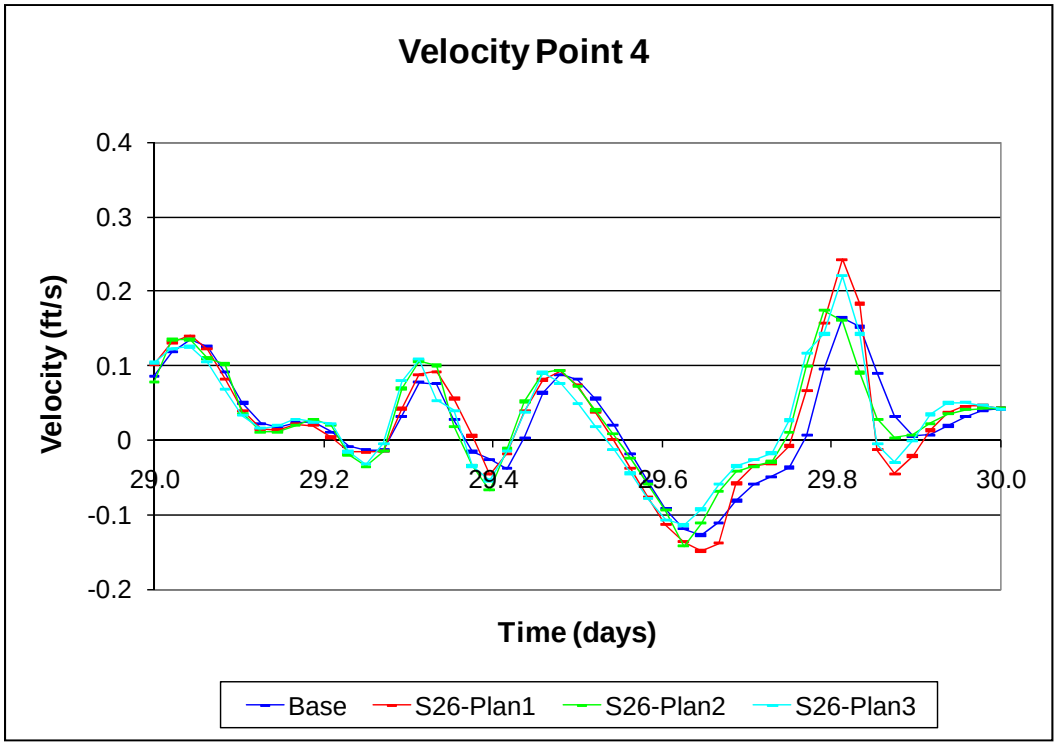

Figure 81. Velocity comparison for day 29 at point 4 for Station 26 plan set.

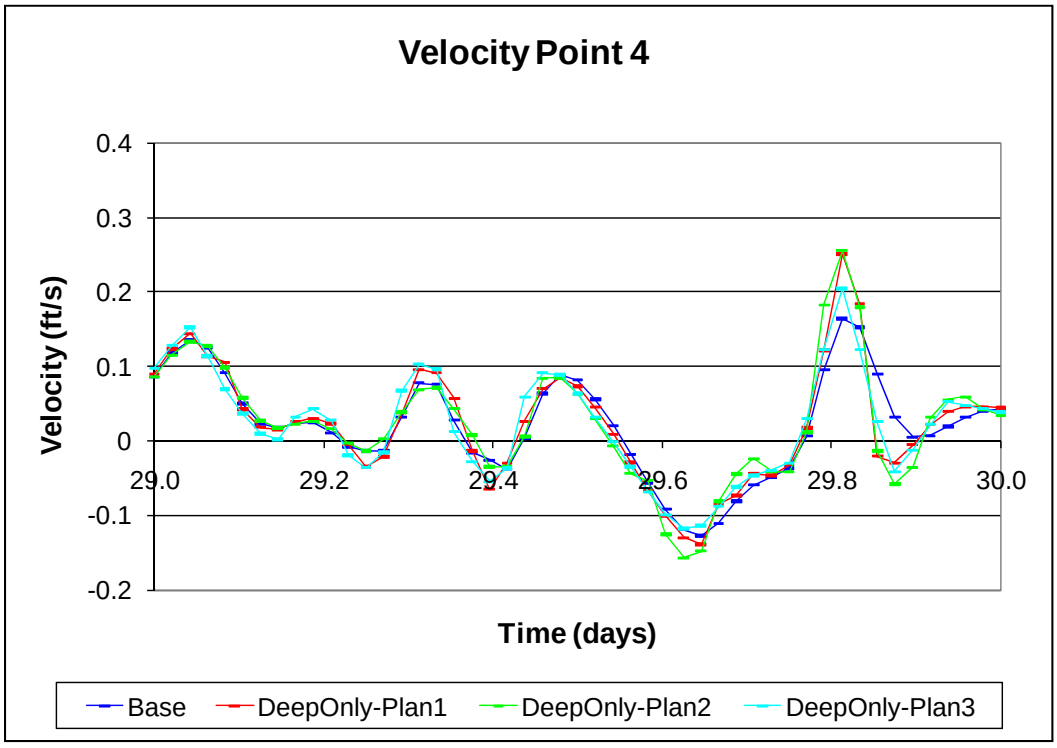

Figure 82. Velocity comparison for day 29 at point 4 for Deepen Only plan set.

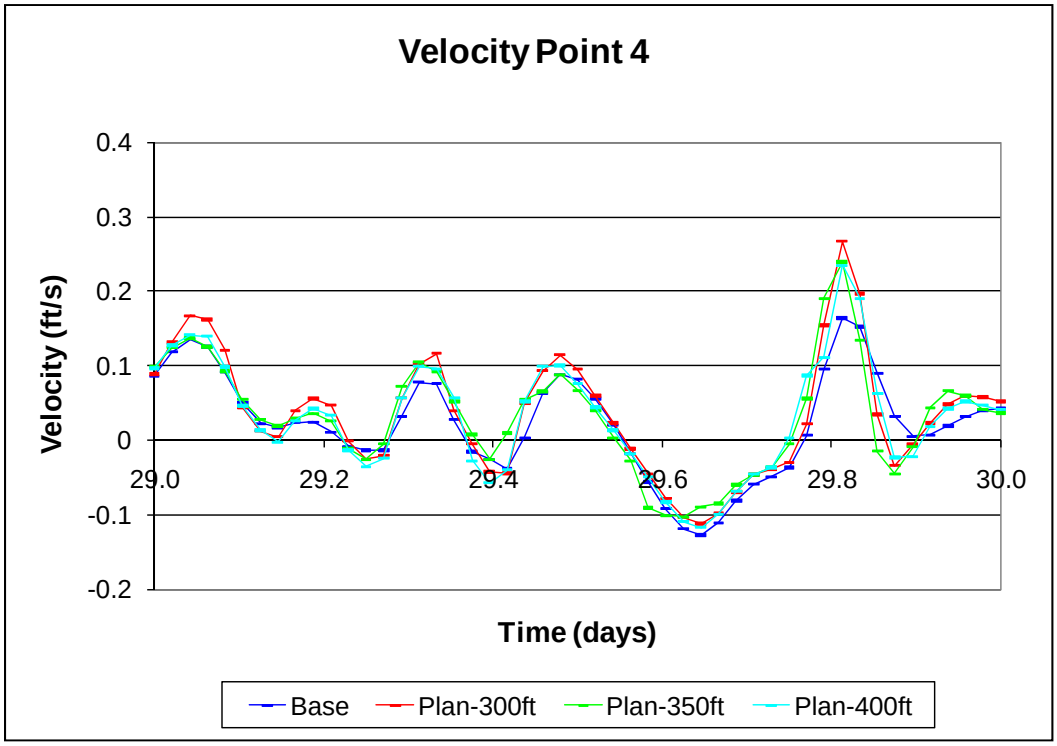

Figure 83. Velocity comparison for day 29 at point 4 for 300/350/400 plan set.

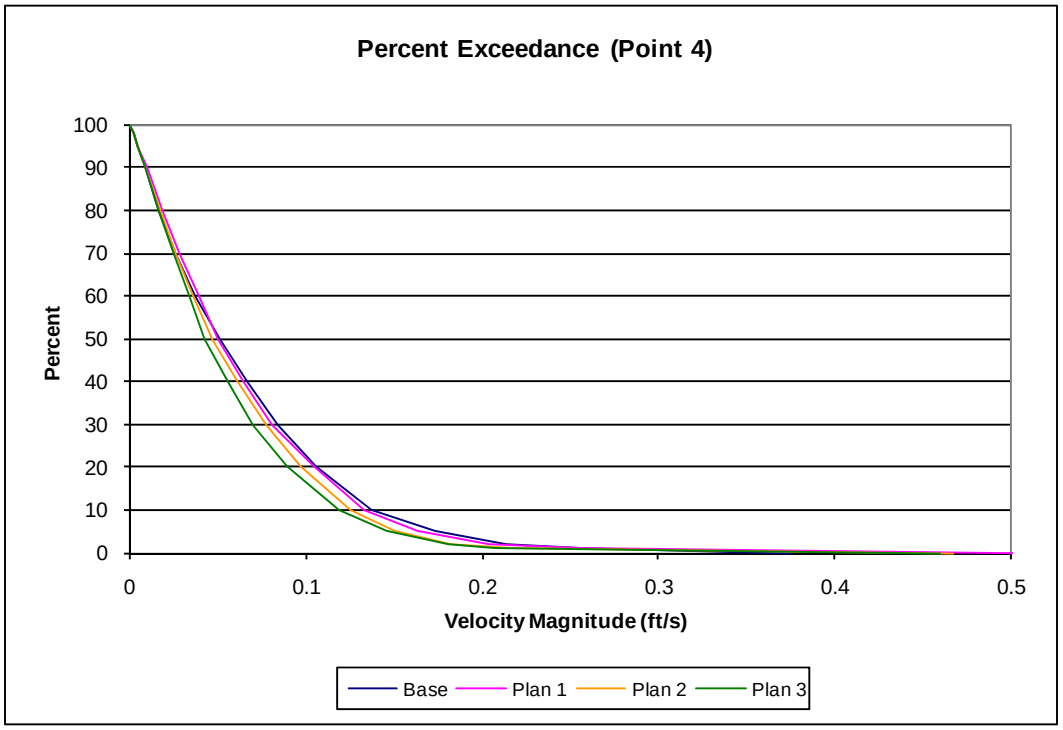

Figure 84. Percent exceedance analysis for point 4 for Initial plan set.

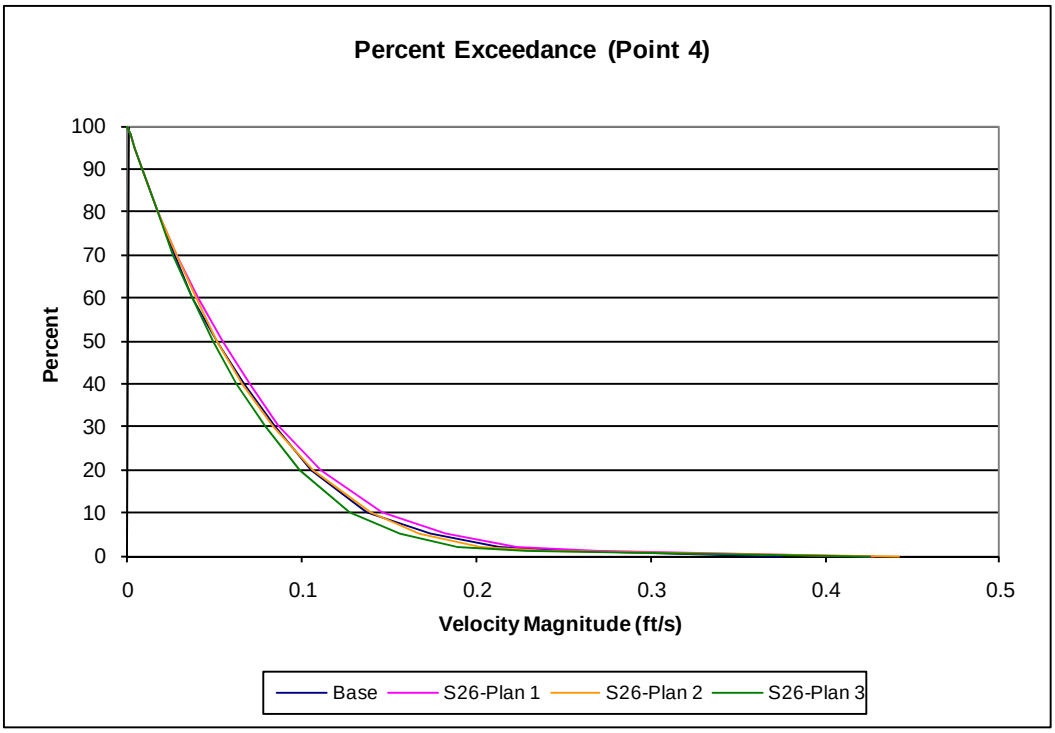

Figure 85. Percent exceedance analysis for point 4 for Station 26 plan set.

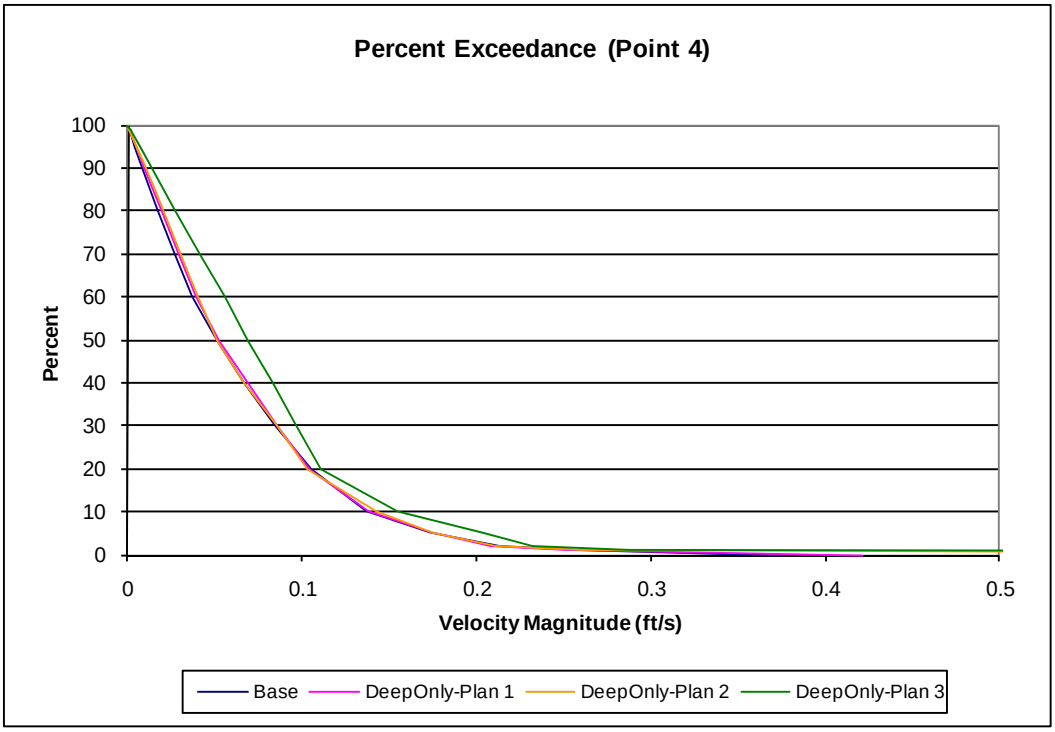

Figure 86. Percent exceedance analysis for point 4 for Deepen Only plan set.

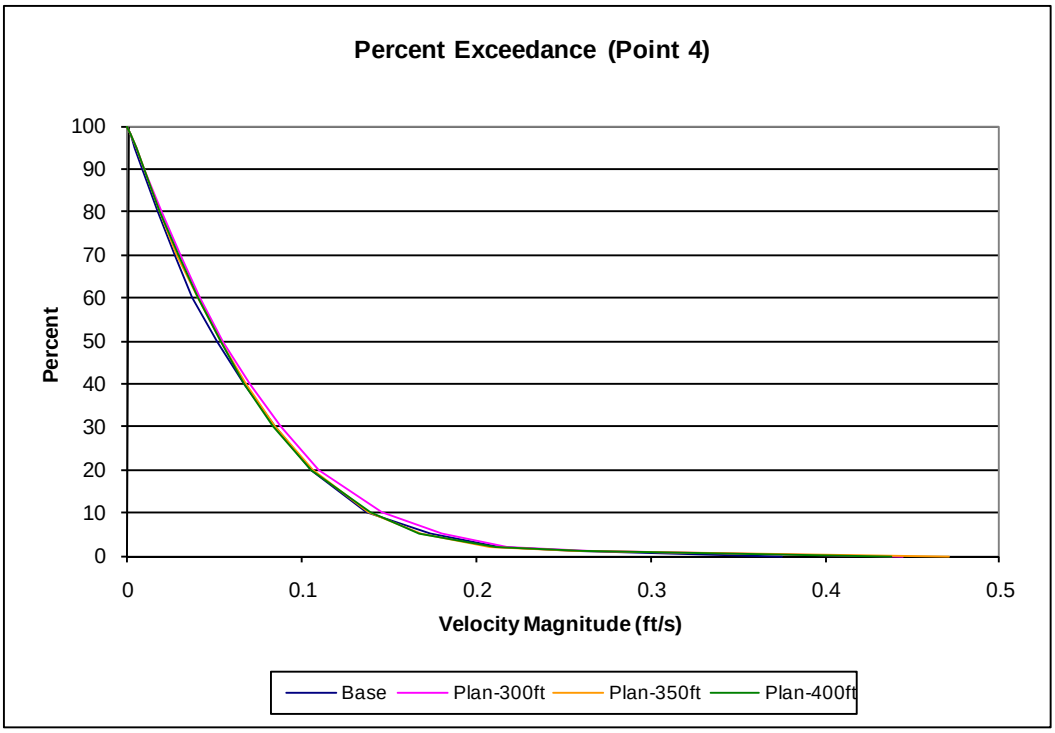

Figure 87. Percent exceedance analysis for point 4 for 300/350/400 plan set.

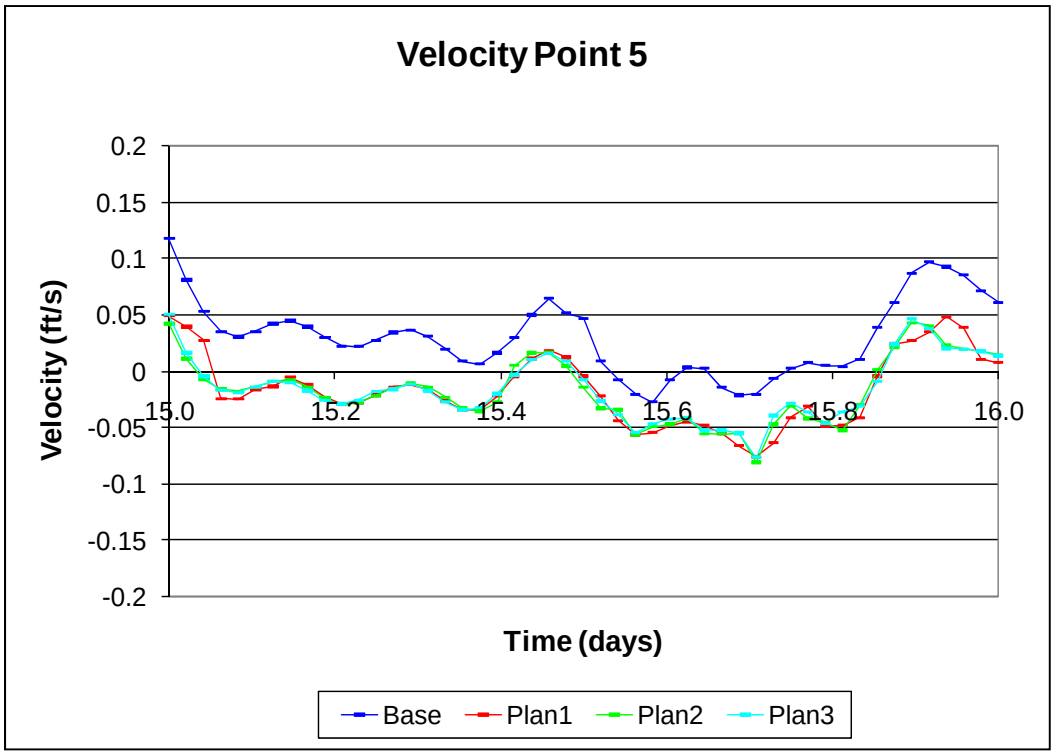

Figure 88. Velocity comparison for day 15 at point 5 for Initial plan set.

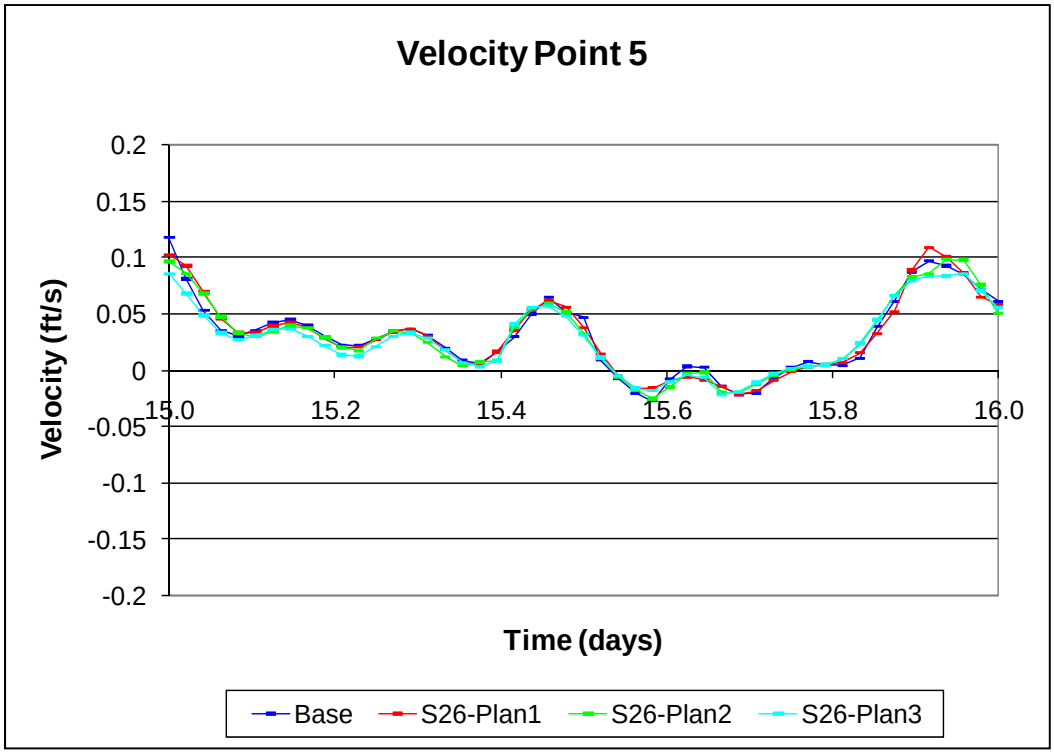

Figure 89. Velocity comparison for day 15 at point 5 for Station 26 plan set.

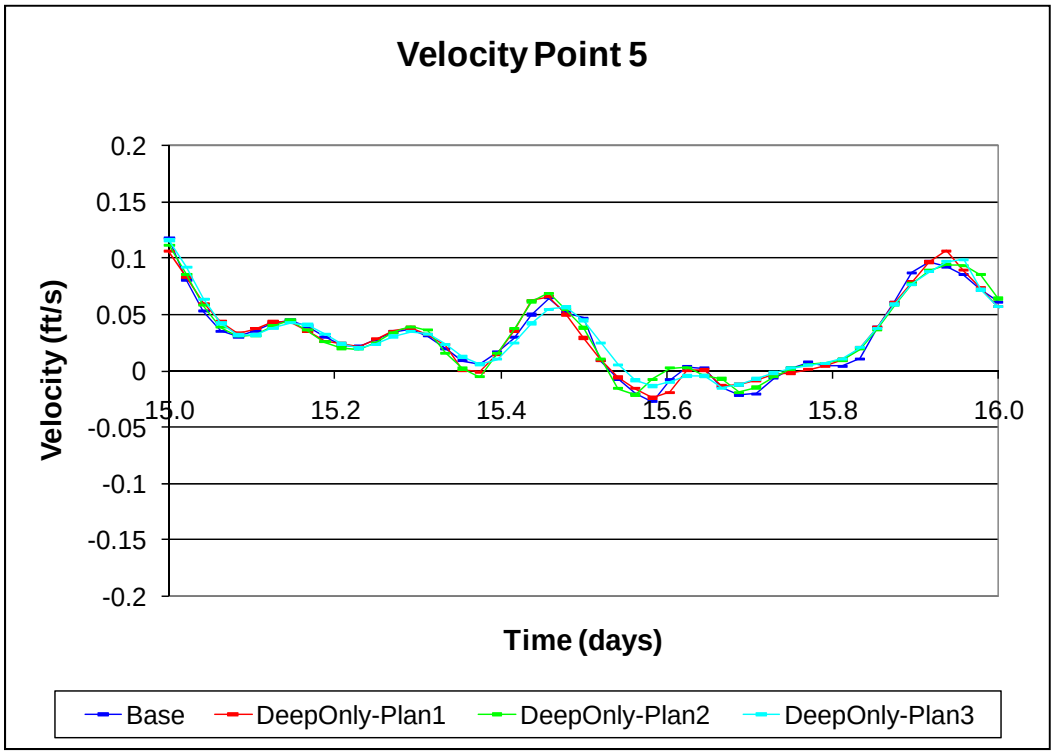

Figure 90. Velocity comparison for day 15 at point 5 for Deepen Only plan set.

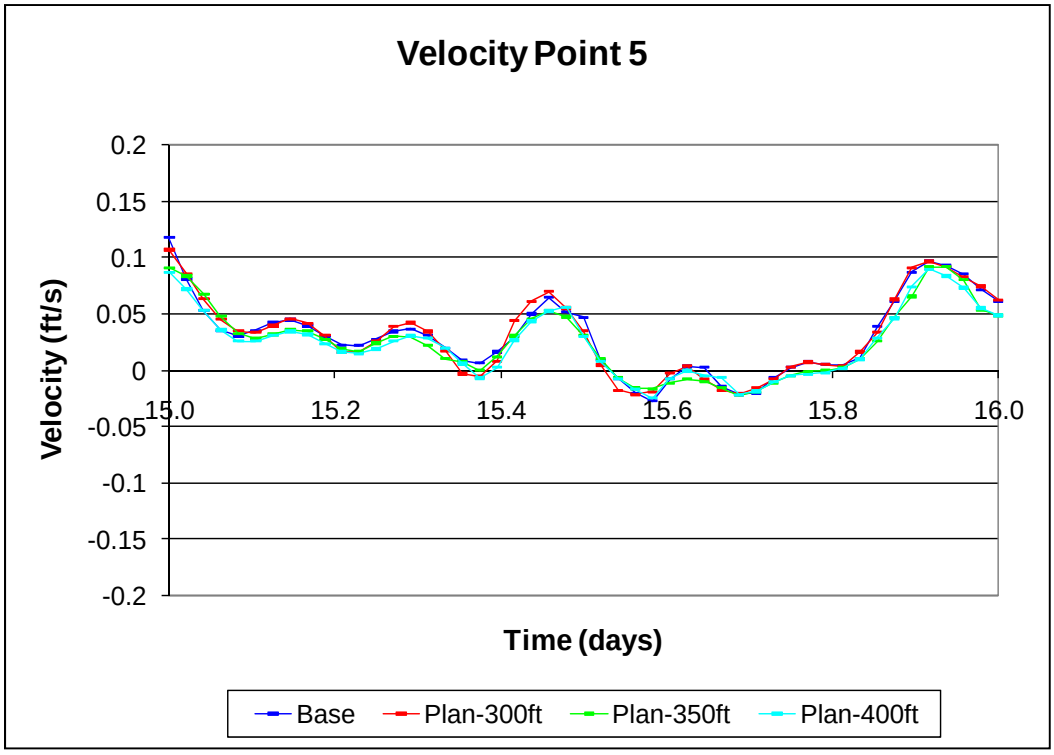

Figure 91. Velocity comparison for day 15 at point 5 for 300/350/400 plan set.

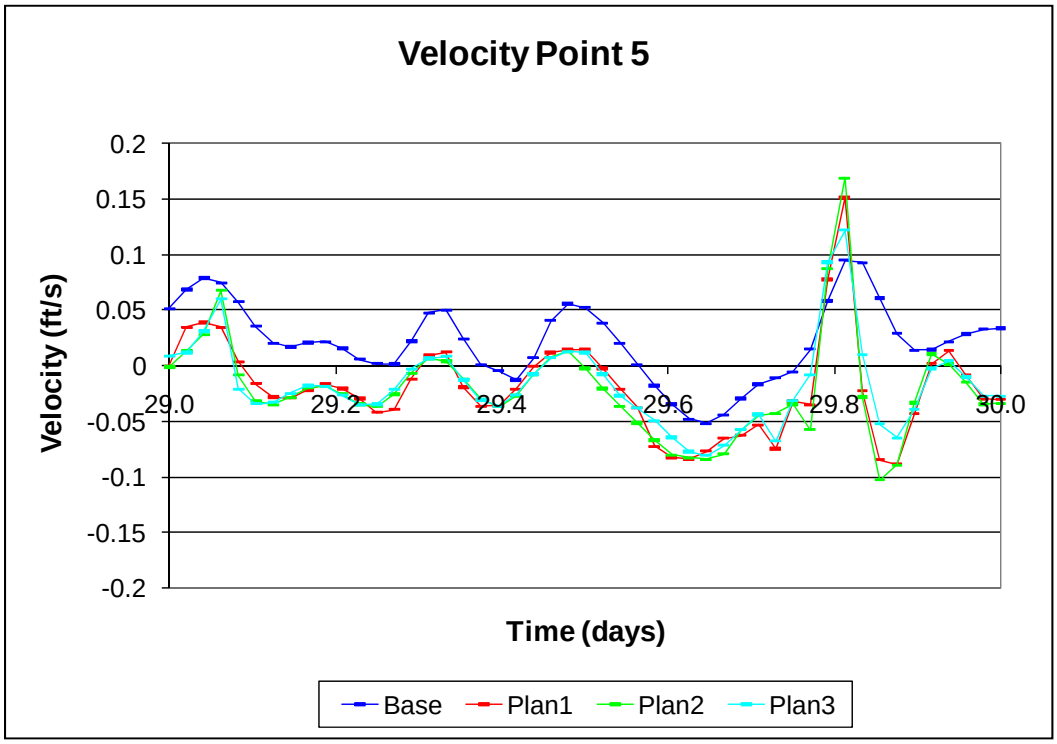

Figure 92. Velocity comparison for day 29 at point 5 for Initial plan set.

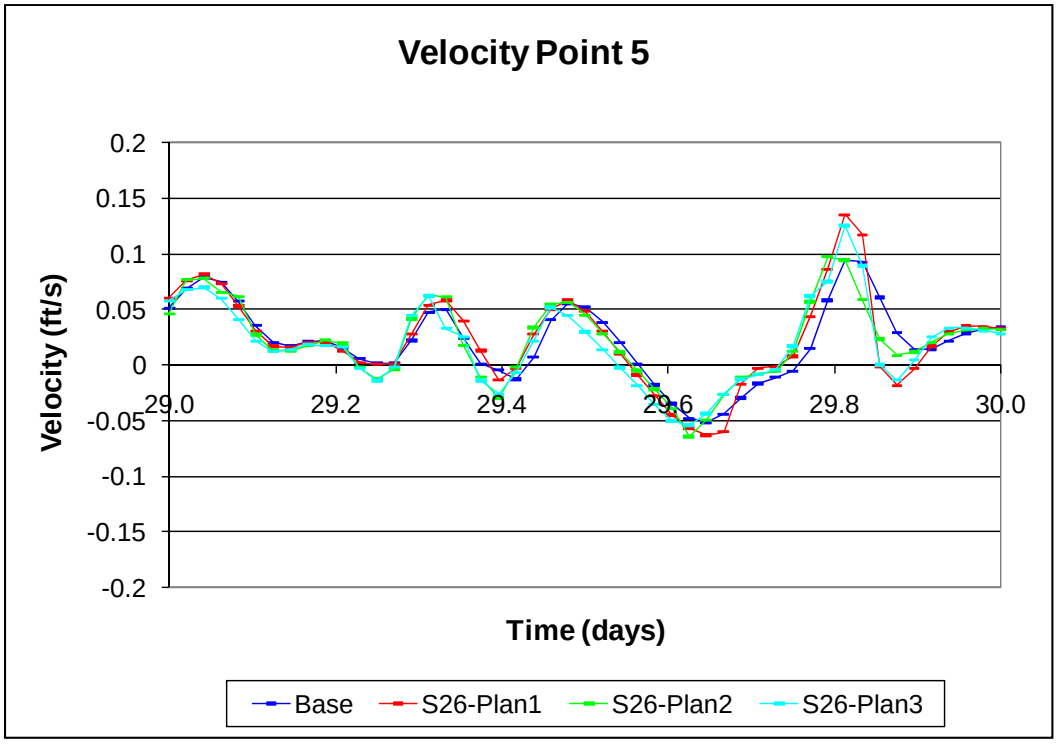

Figure 93. Velocity comparison for day 29 at point 5 for Station 26 plan set.

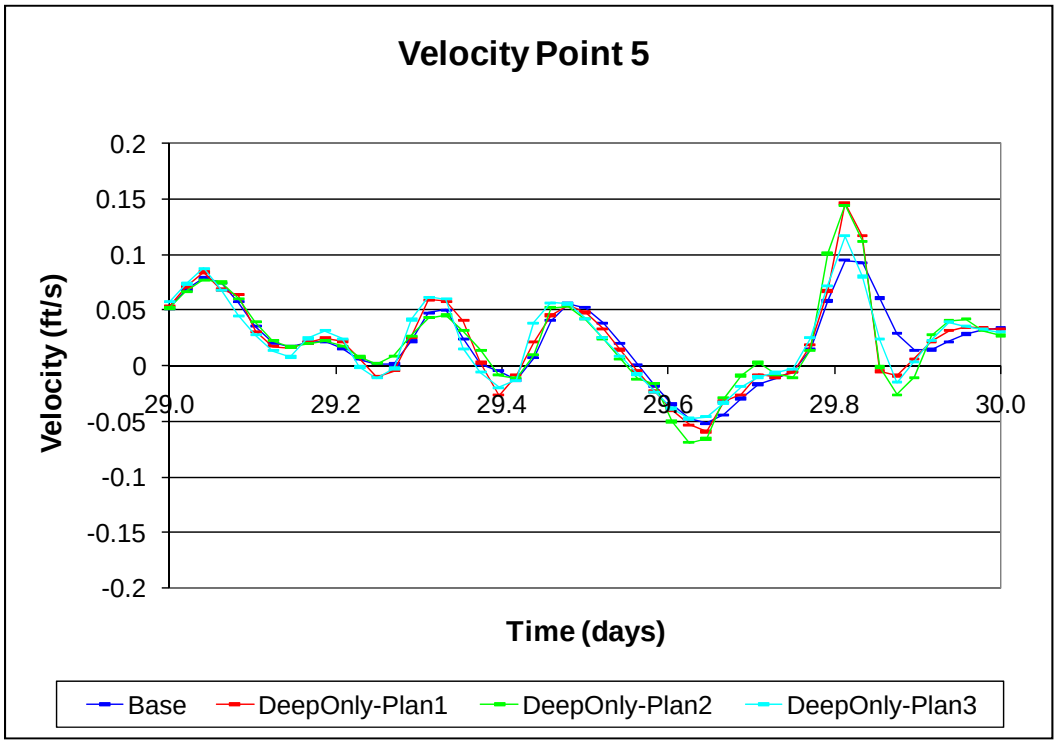

Figure 94. Velocity comparison for day 29 at point 5 for Deepen Only plan set.

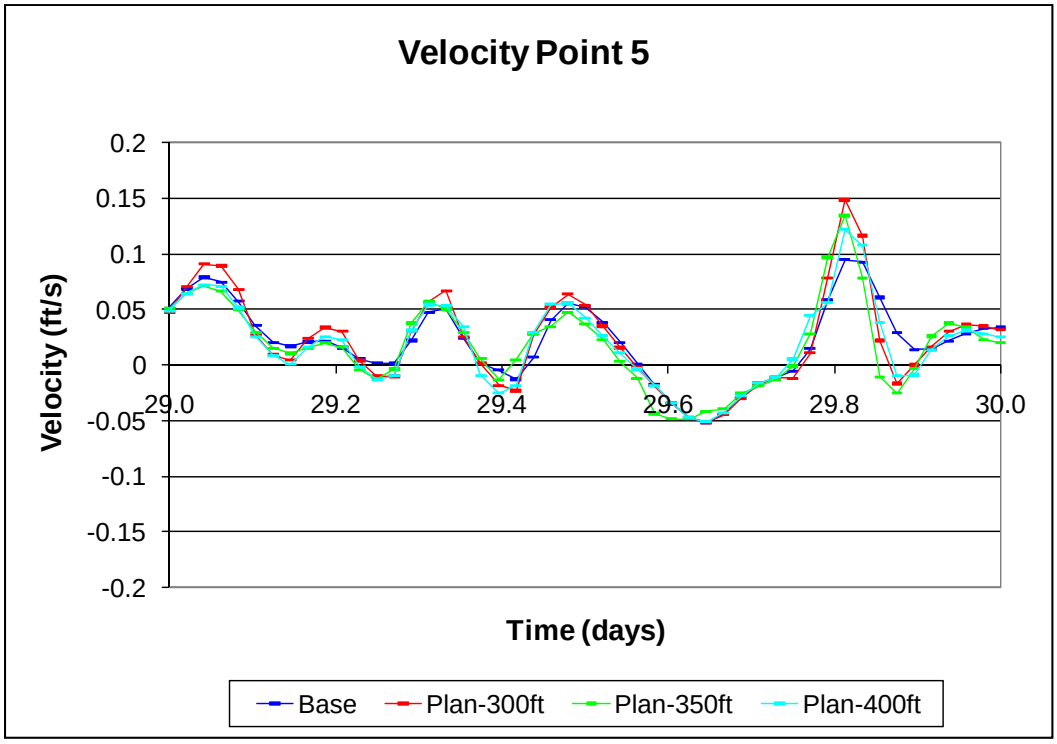

Figure 95. Velocity comparison for day 29 at point 5 for 300/350/400 plan set.

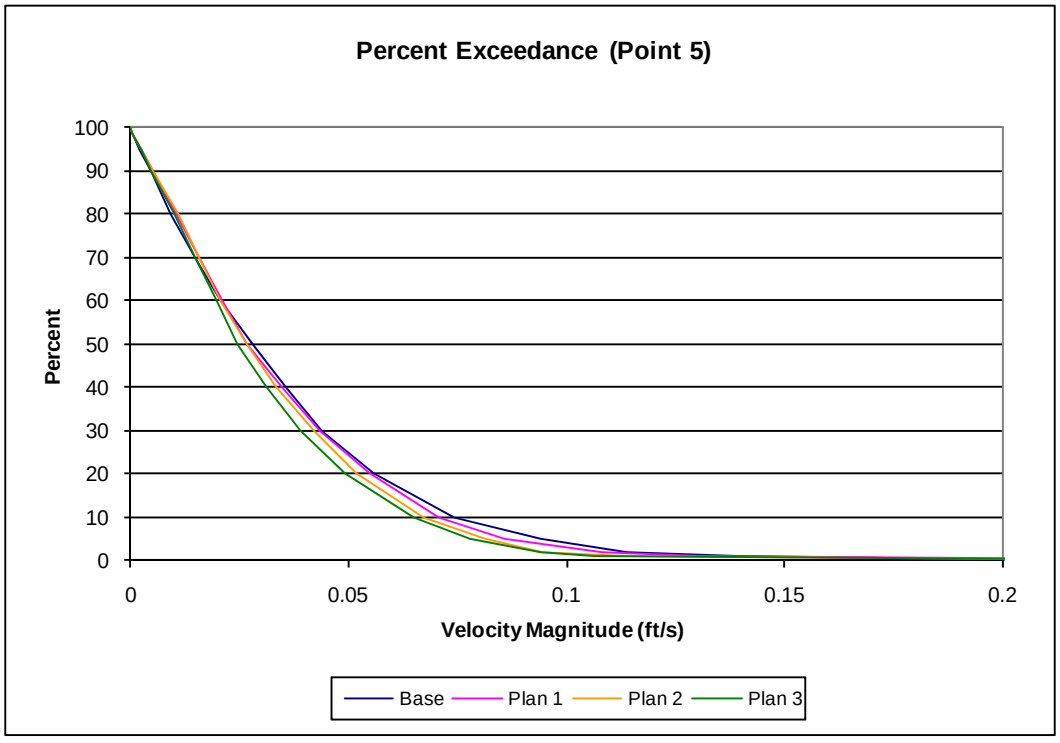

Figure 96. Percent exceedance analysis for point 5 for Initial plan set.

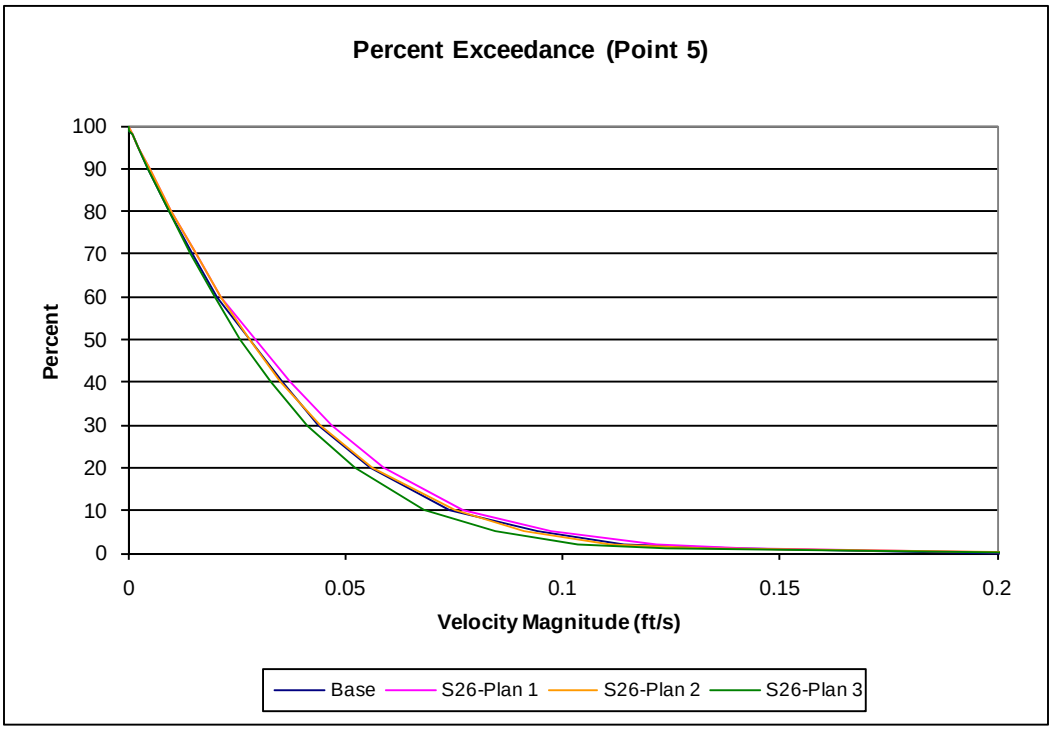

Figure 97. Percent exceedance analysis for point 5 for Station 26 plan set.

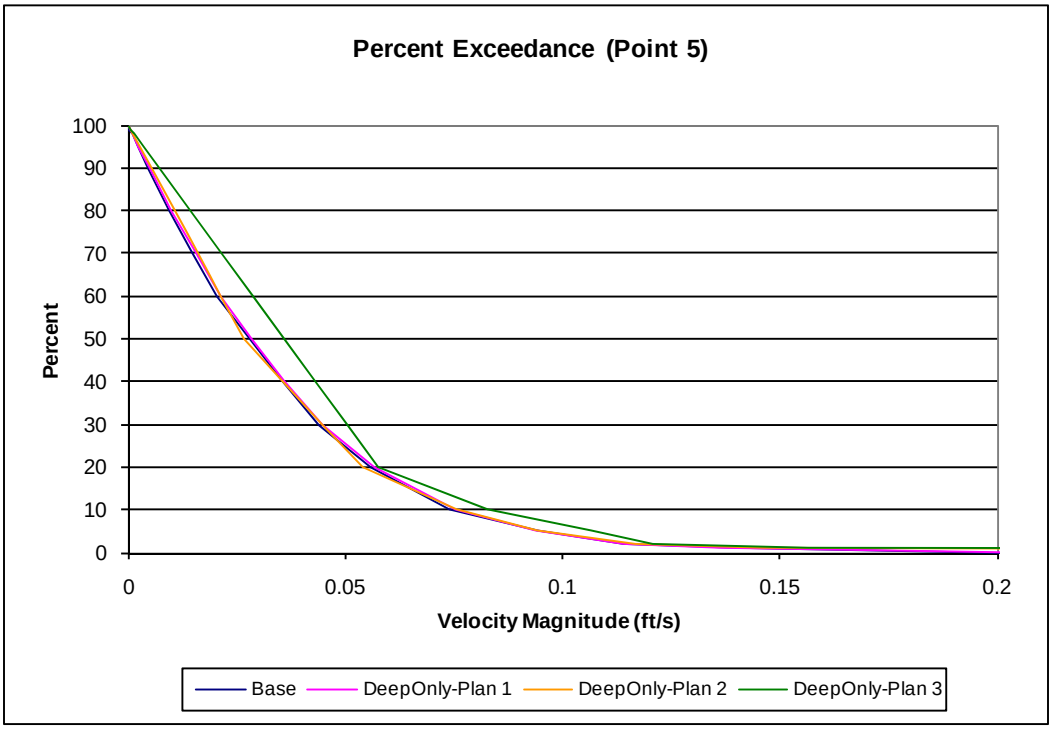

Figure 98. Percent exceedance analysis for point 5 for Deepen Only plan set.

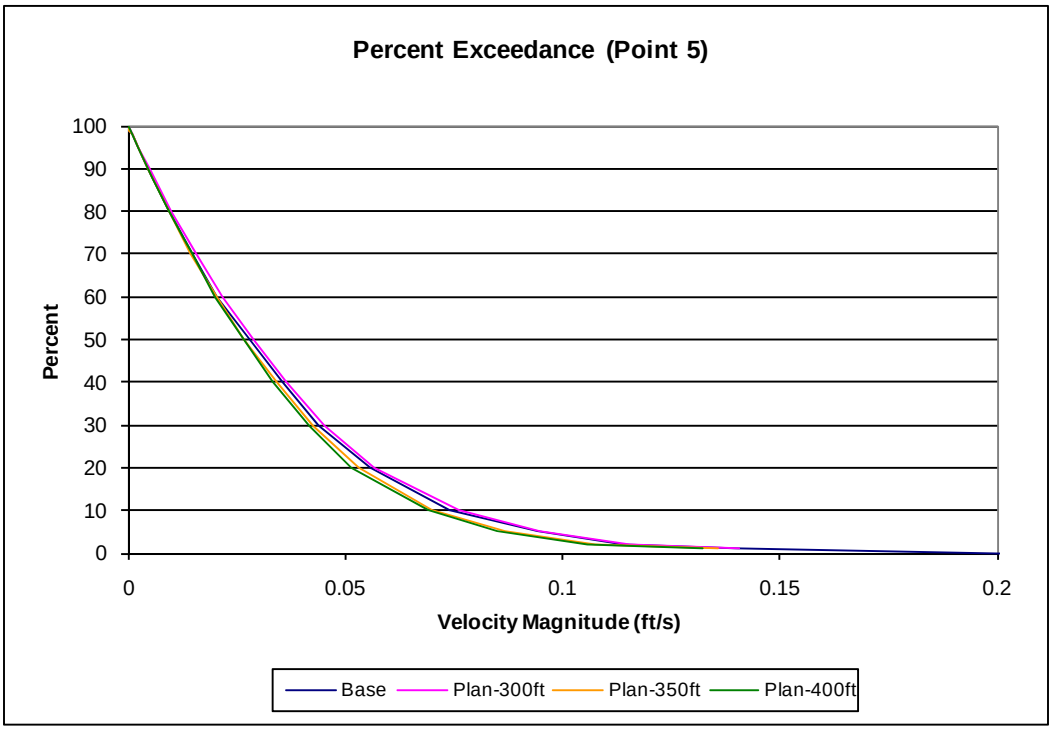

Figure 99. Percent exceedance analysis for point 5 for 300/350/400 plan set.

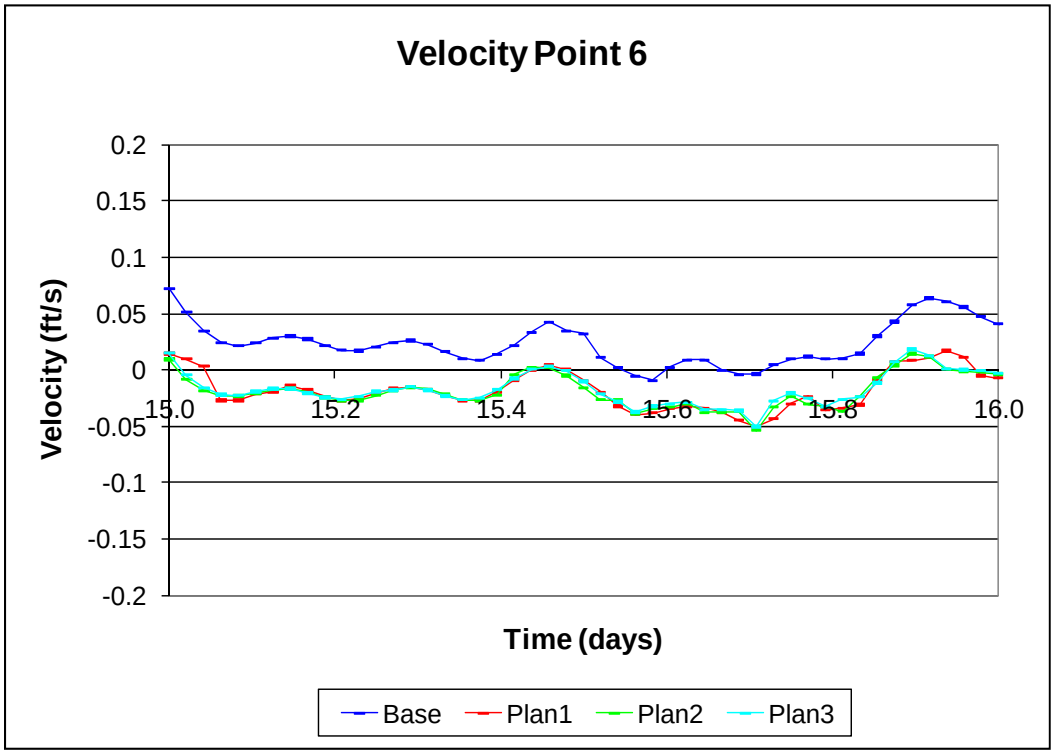

Figure 100. Velocity comparison for day 15 at point 6 for Initial plan set.

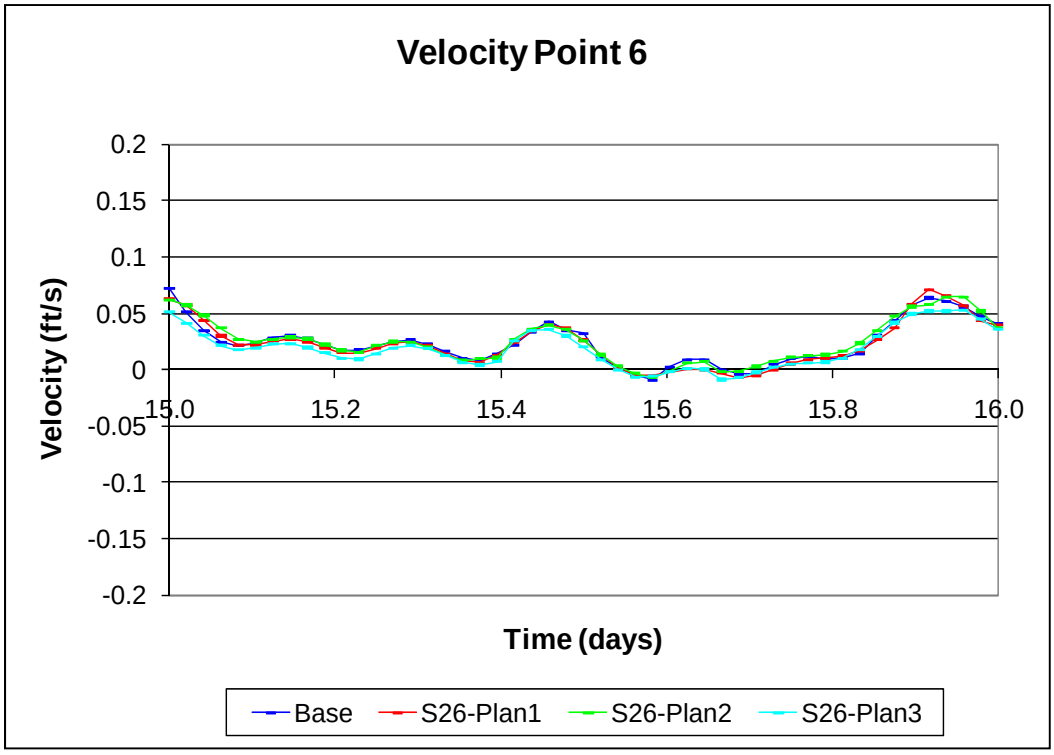

Figure 101. Velocity comparison for day 15 at point 6 for Station 26 plan set.

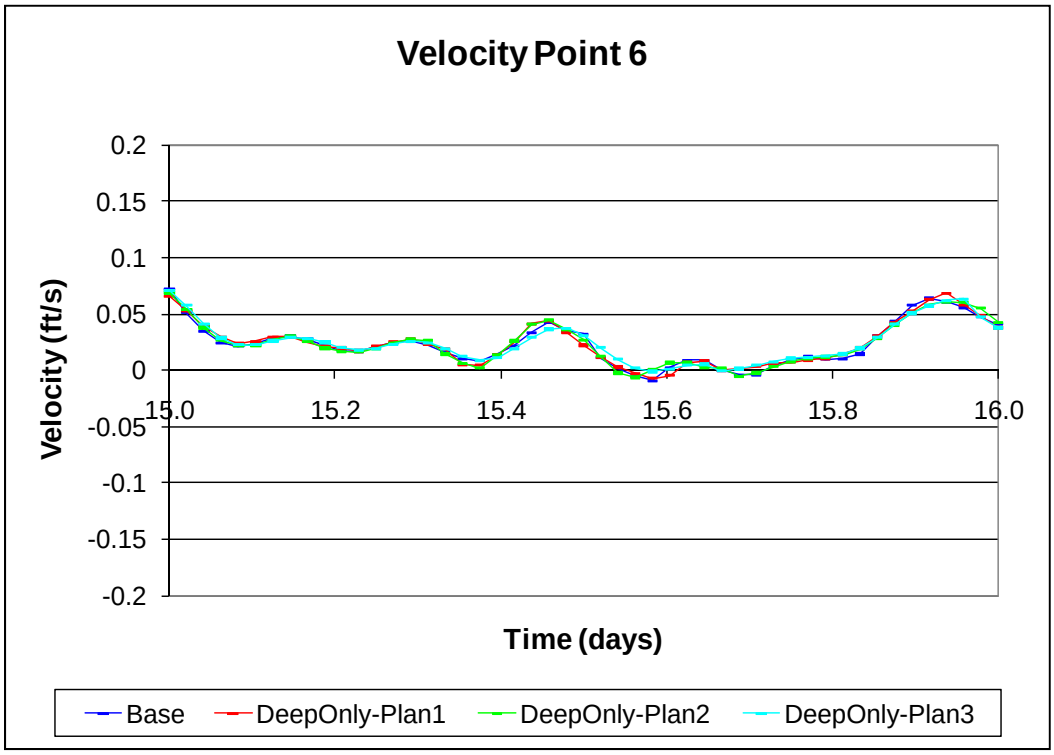

Figure 102. Velocity comparison for day 15 at point 6 for Deepen Only plan set.

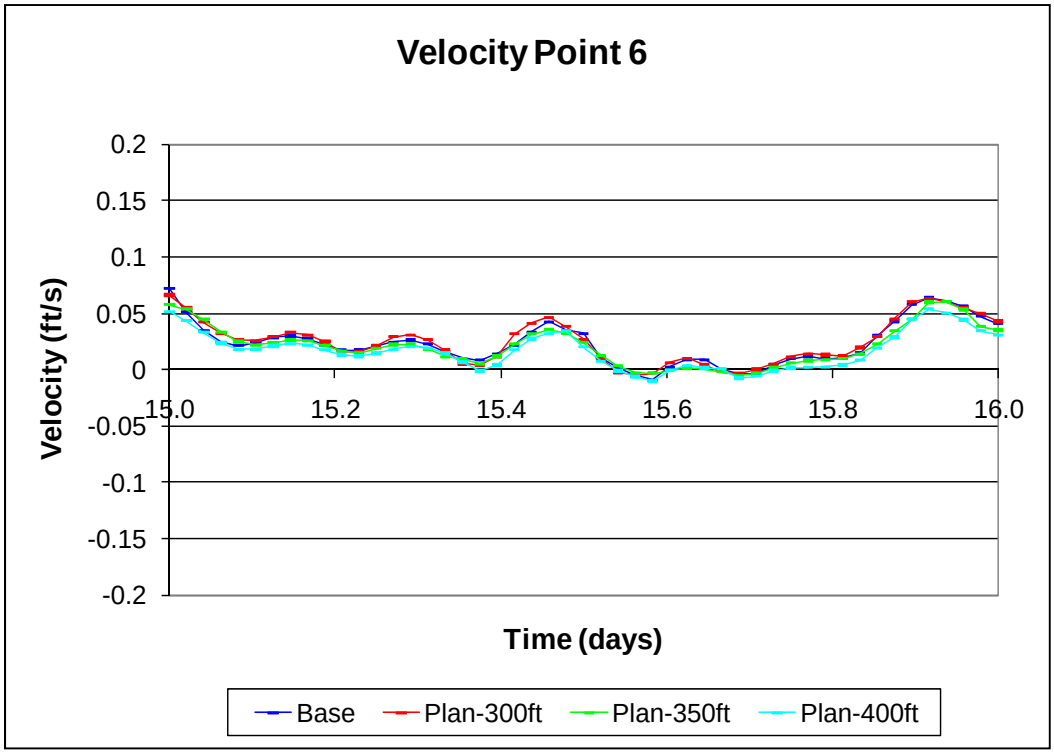

Figure 103. Velocity comparison for day 15 at point 6 for 300/350/400 plan set.

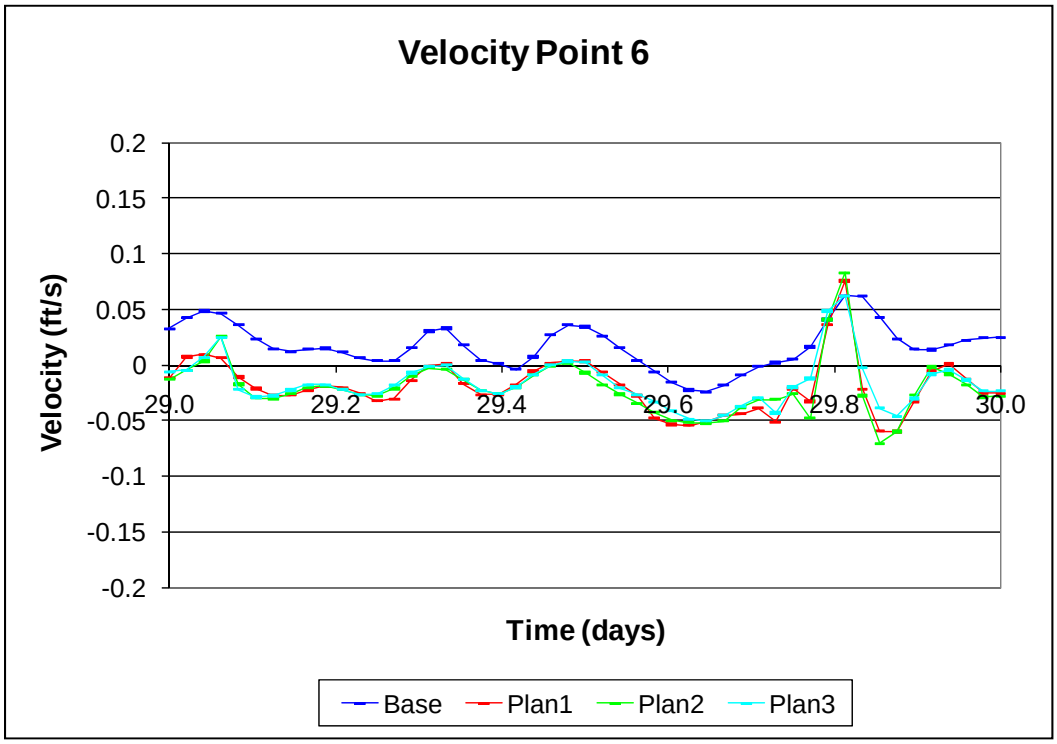

Figure 104. Velocity comparison for day 29 at point 6 for Initial plan set.

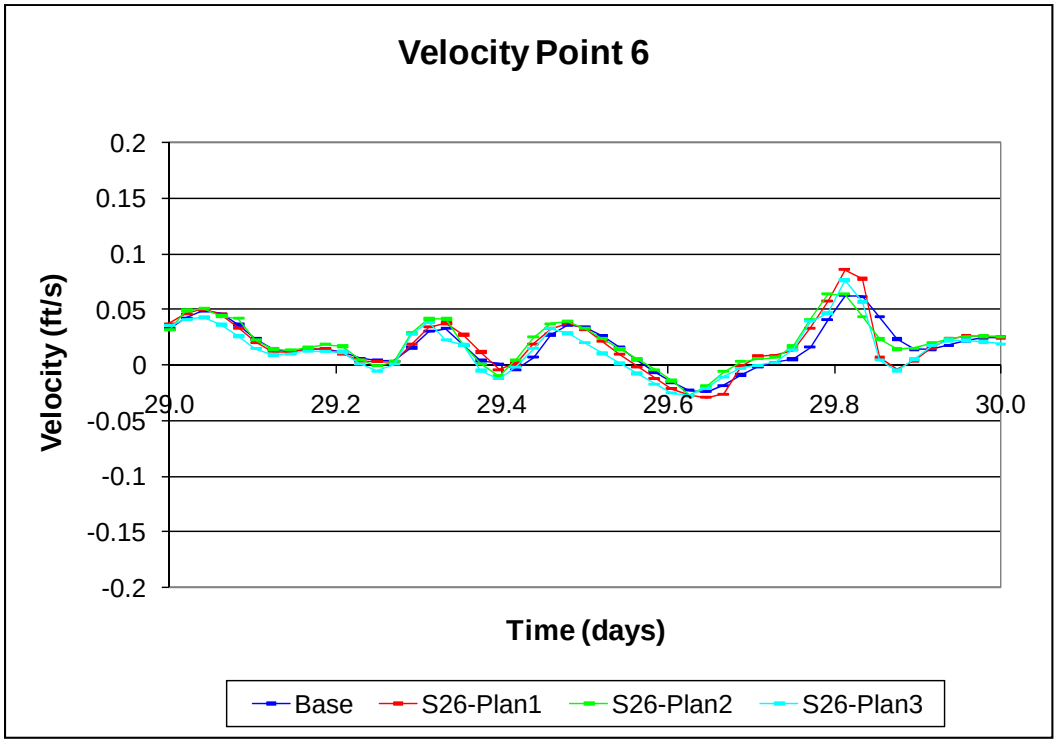

Figure 105. Velocity comparison for day 29 at point 6 for Station 26 plan set.

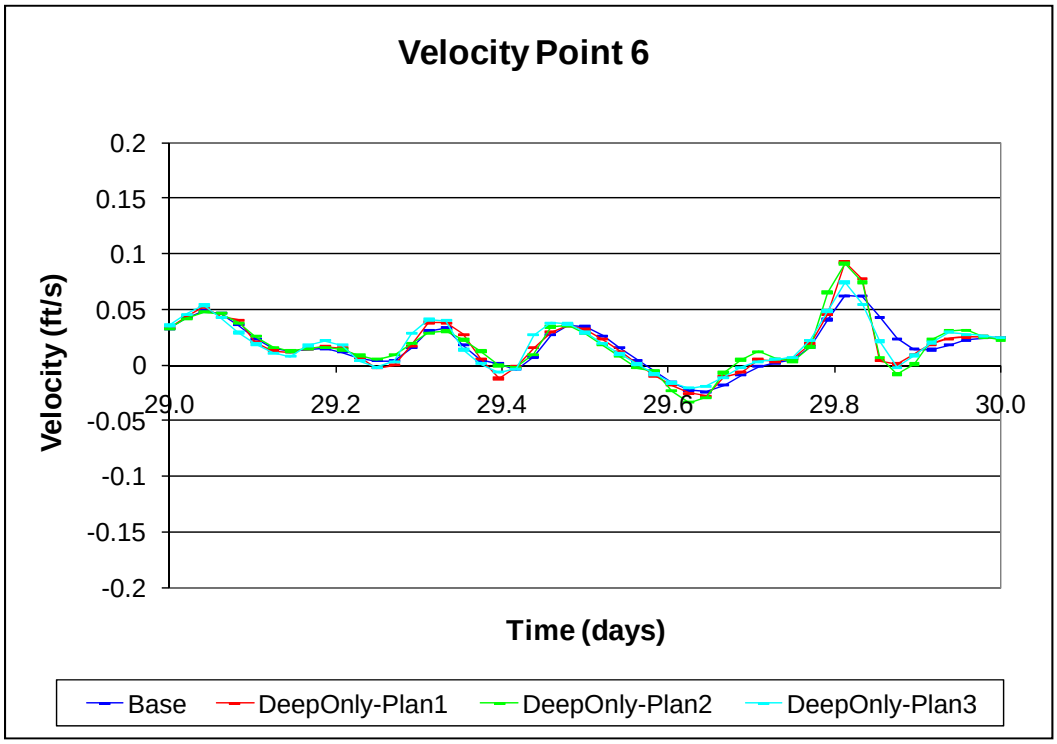

Figure 106. Velocity comparison for day 29 at point 6 for Deepen Only plan set.

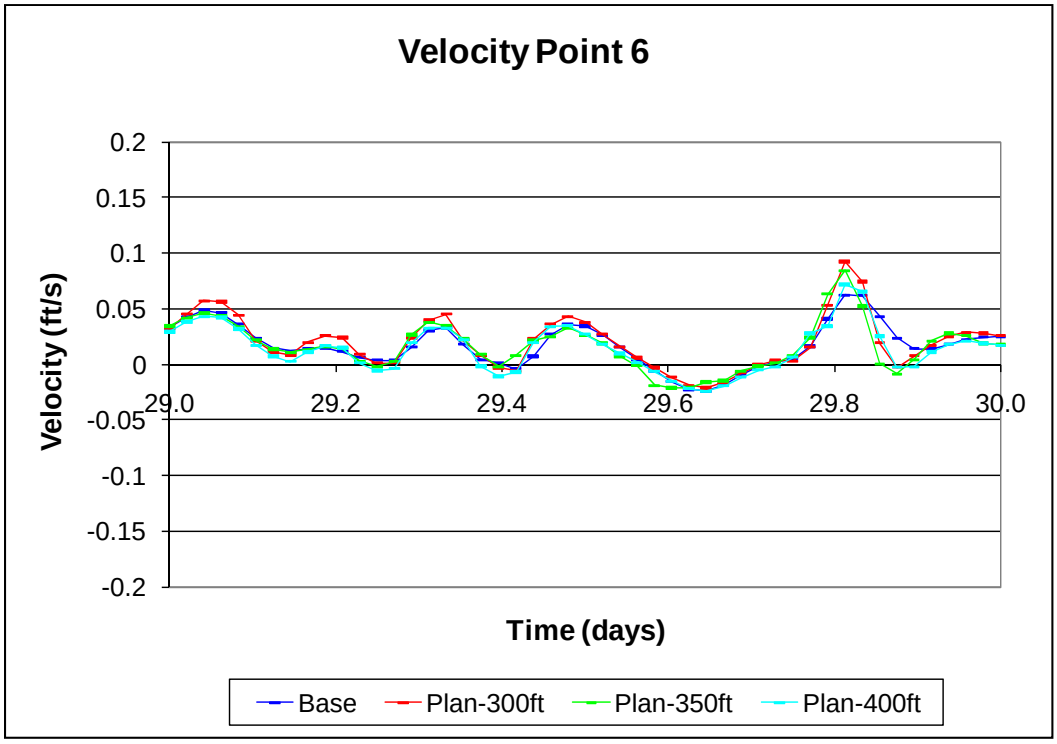

Figure 107. Velocity comparison for day 29 at point 6 for 300/350/400 plan set.

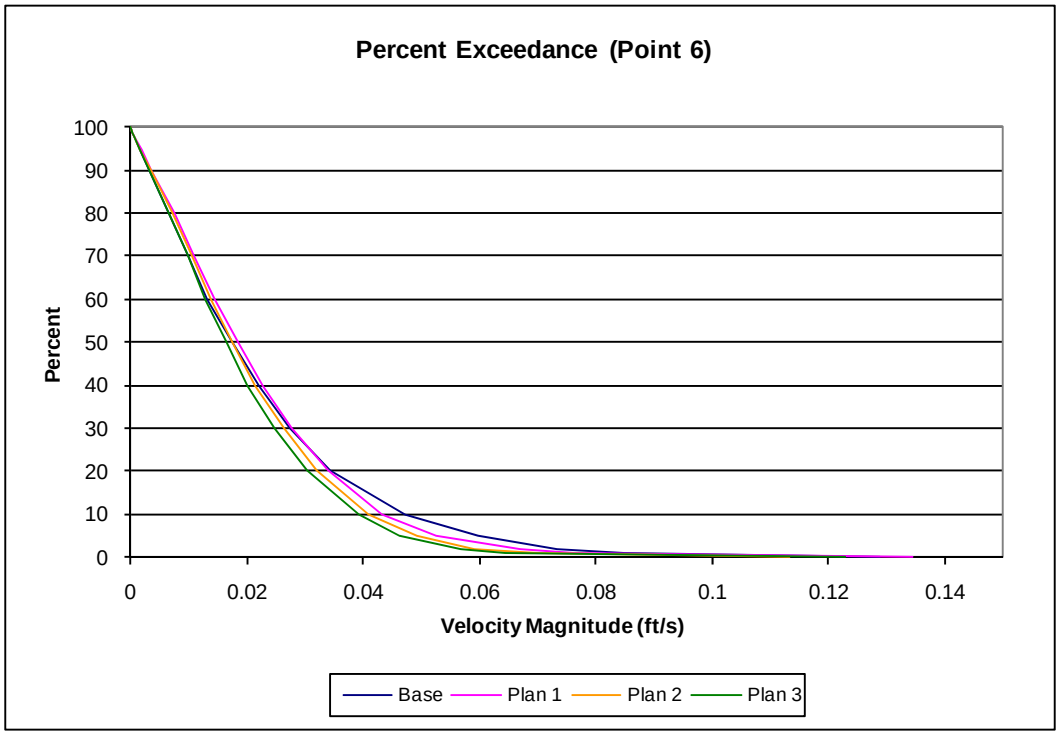

Figure 108. Percent exceedance analysis for point 6 for Initial plan set.

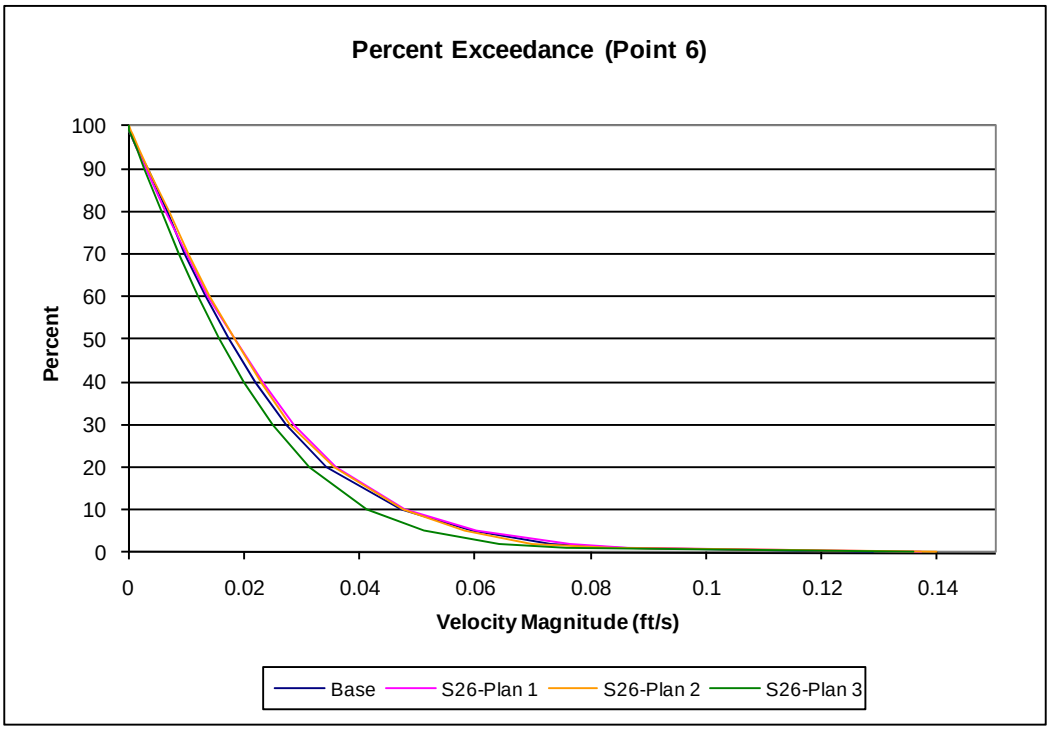

Figure 109. Percent exceedance analysis for point 6 for Station 26 plan set.

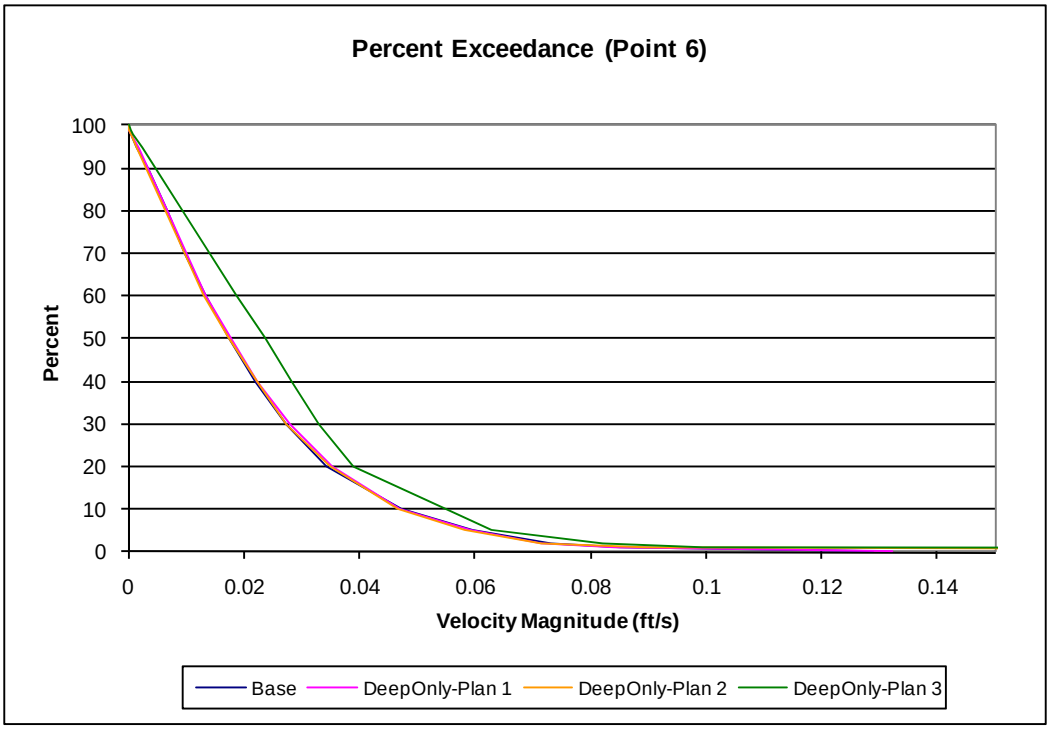

Figure 110. Percent exceedance analysis for point 6 for Deepen Only plan set.

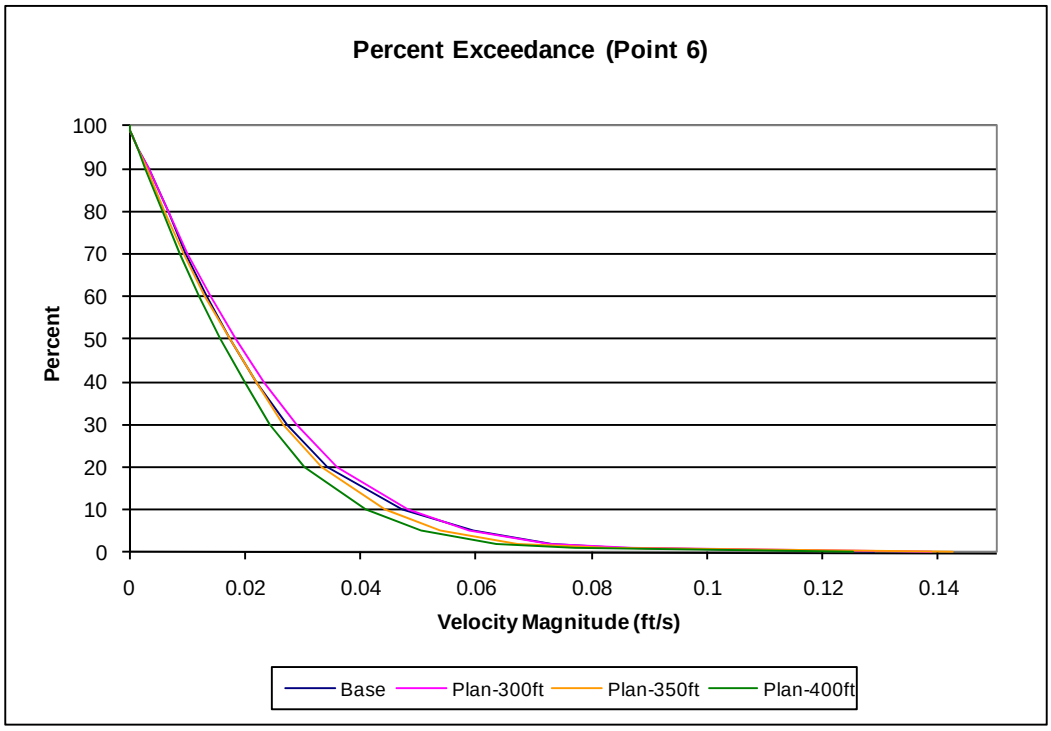

Figure 111. Percent exceedance analysis for point 6 for 300/350/400 plan set.

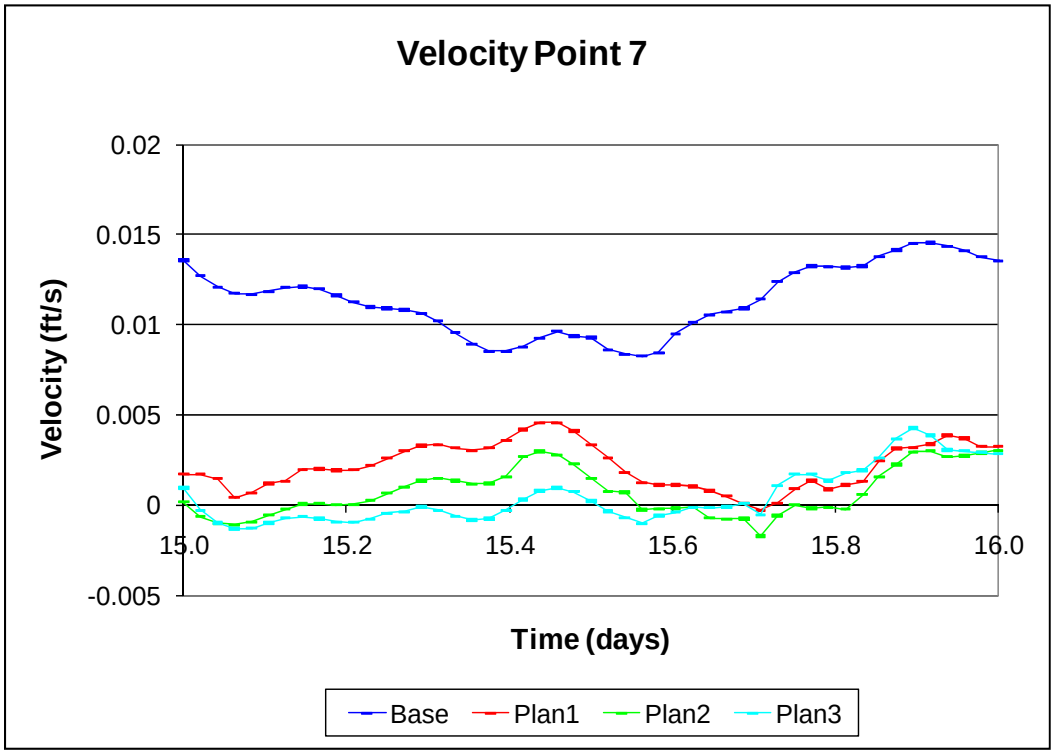

Figure 112. Velocity comparison for day 15 at point 7 for Initial plan set.

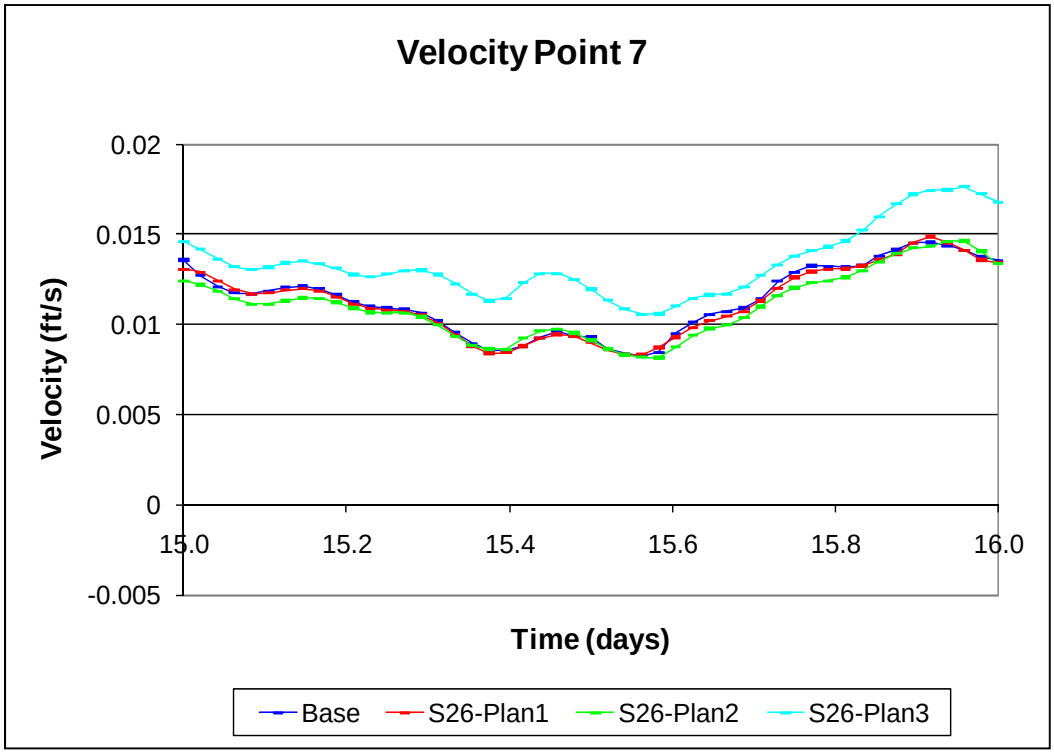

Figure 113. Velocity comparison for day 15 at point 7 for Station 26 plan set.

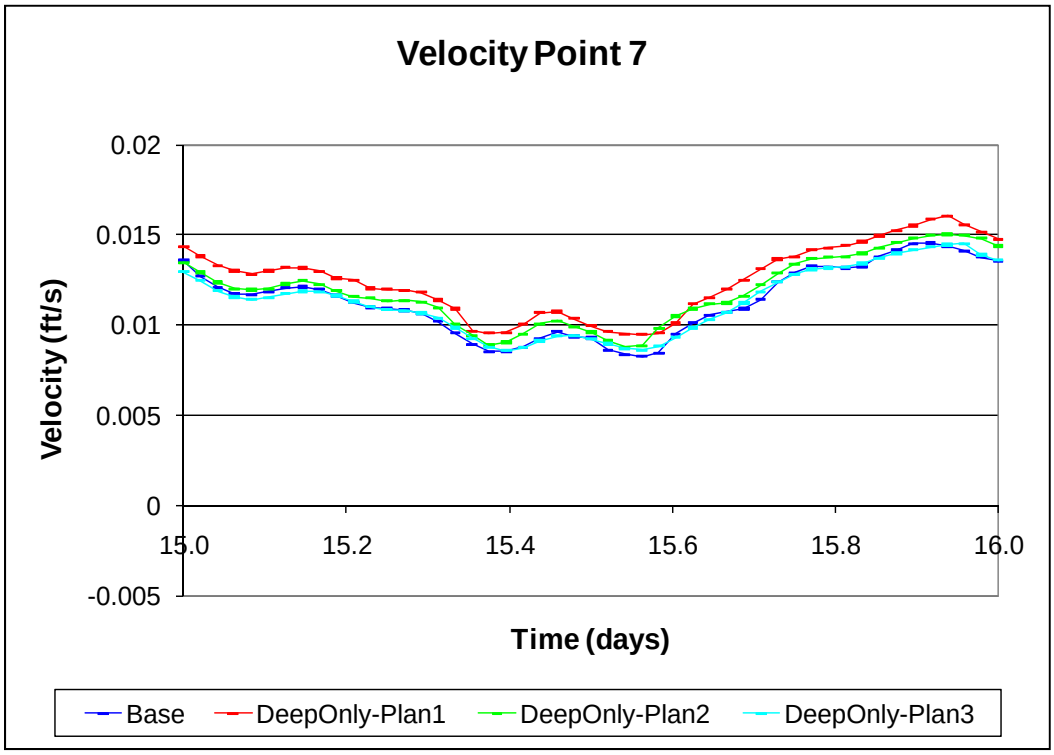

Figure 114. Velocity comparison for day 15 at point 7 for Deepen Only plan set.

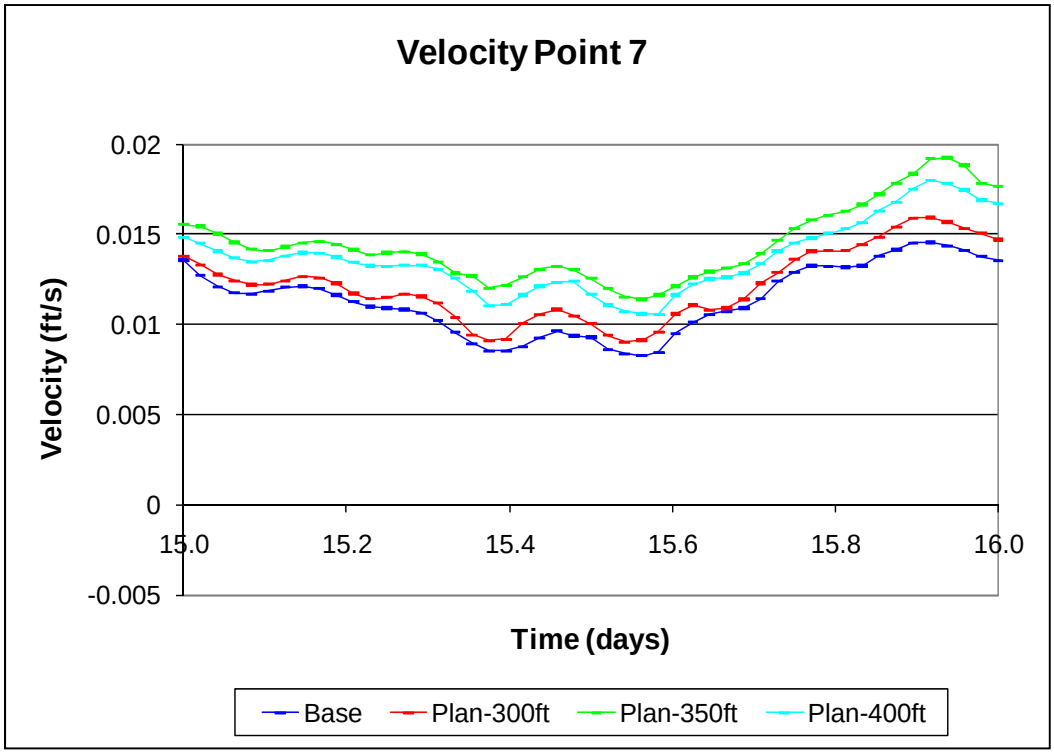

Figure 115. Velocity comparison for day 15 at point 7 for 300/350/400 plan set.

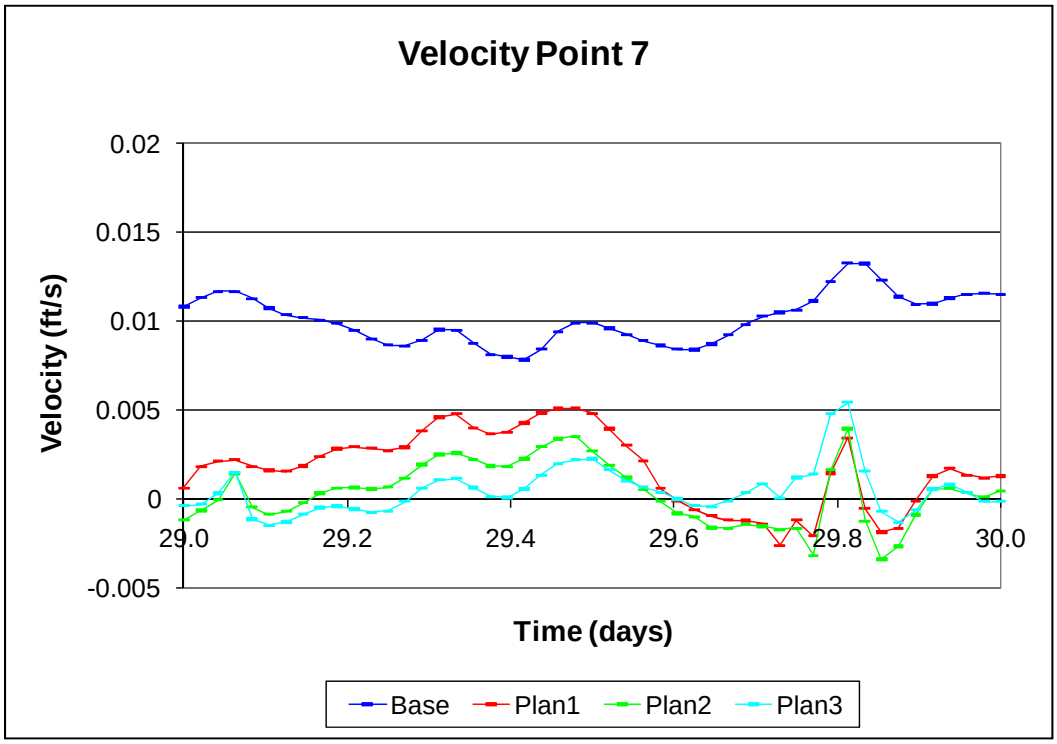

Figure 116. Velocity comparison for day 29 at point 7 for Initial plan set.

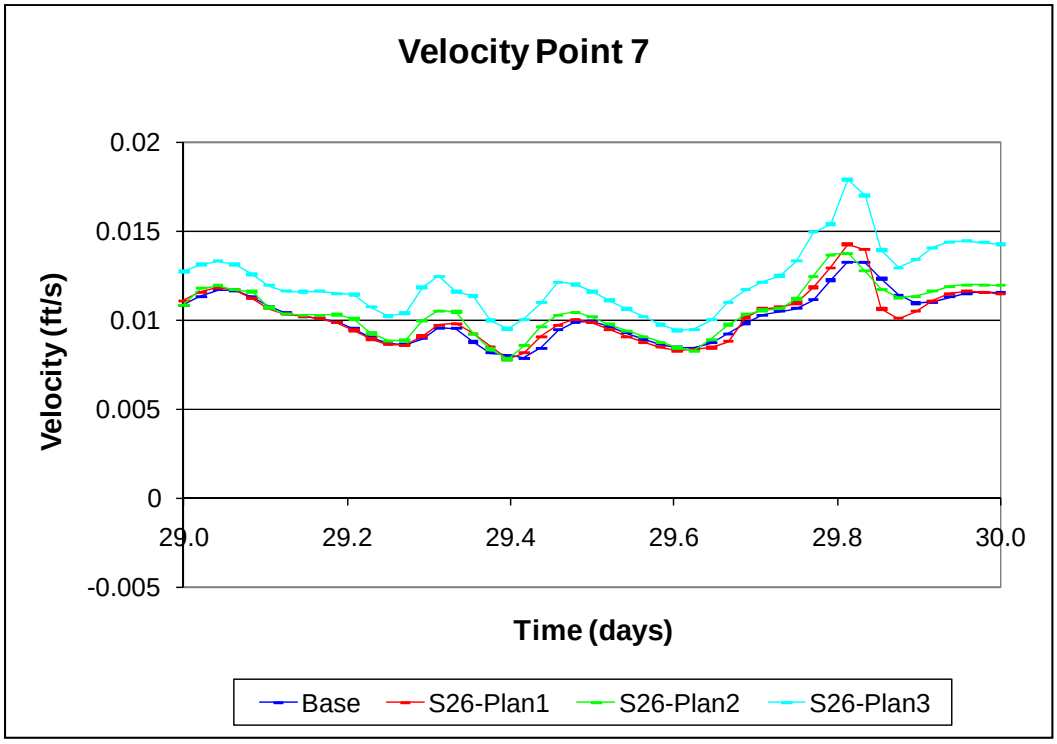

Figure 117. Velocity comparison for day 29 at point 7 for Station 26 plan set.

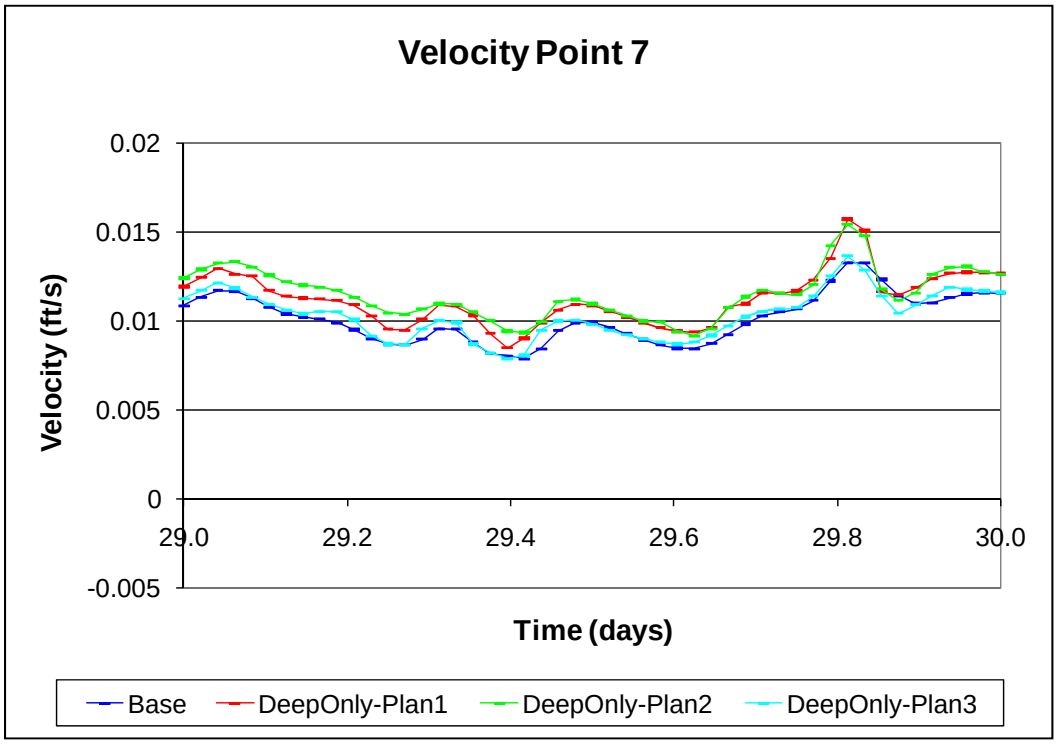

Figure 118. Velocity comparison for day 29 at point 7 for Deepen Only plan set.

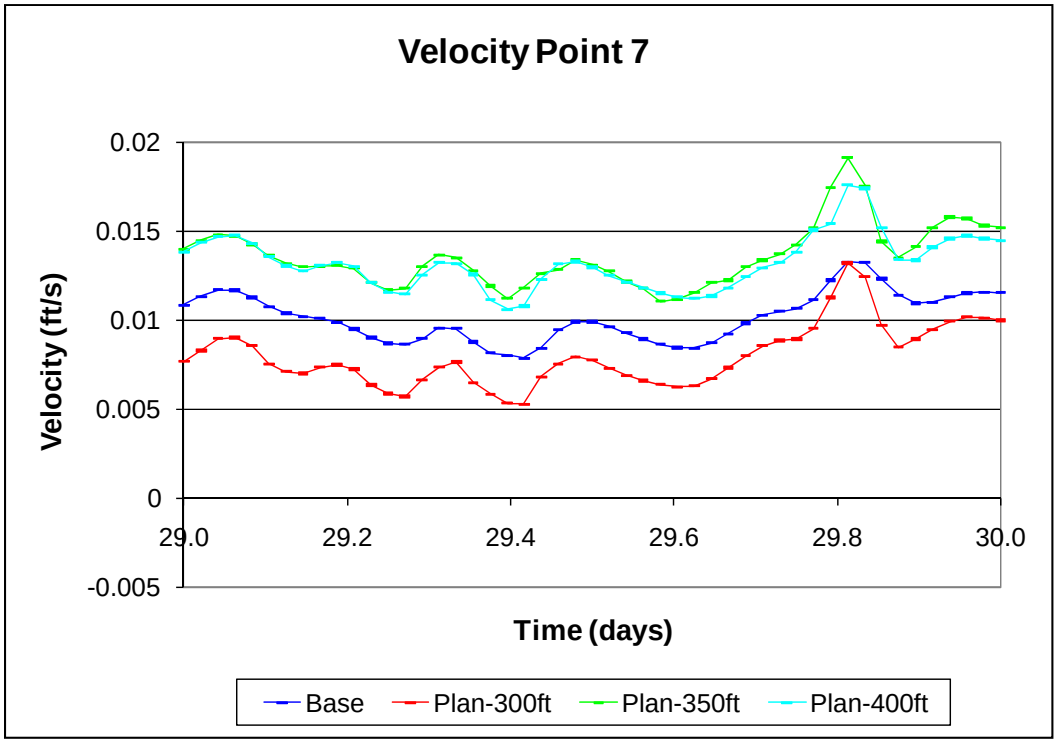

Figure 119. Velocity comparison for day 29 at point 7 for 300/350/400 plan set.

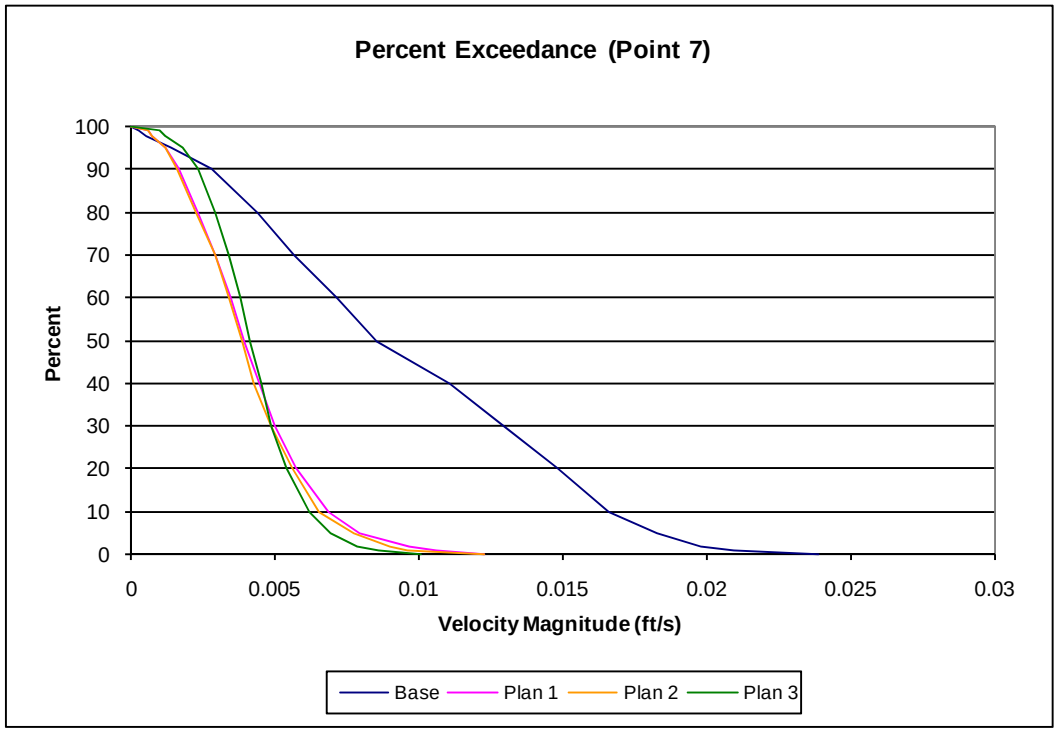

Figure 120. Percent exceedance analysis for point 7 for Initial plan set.

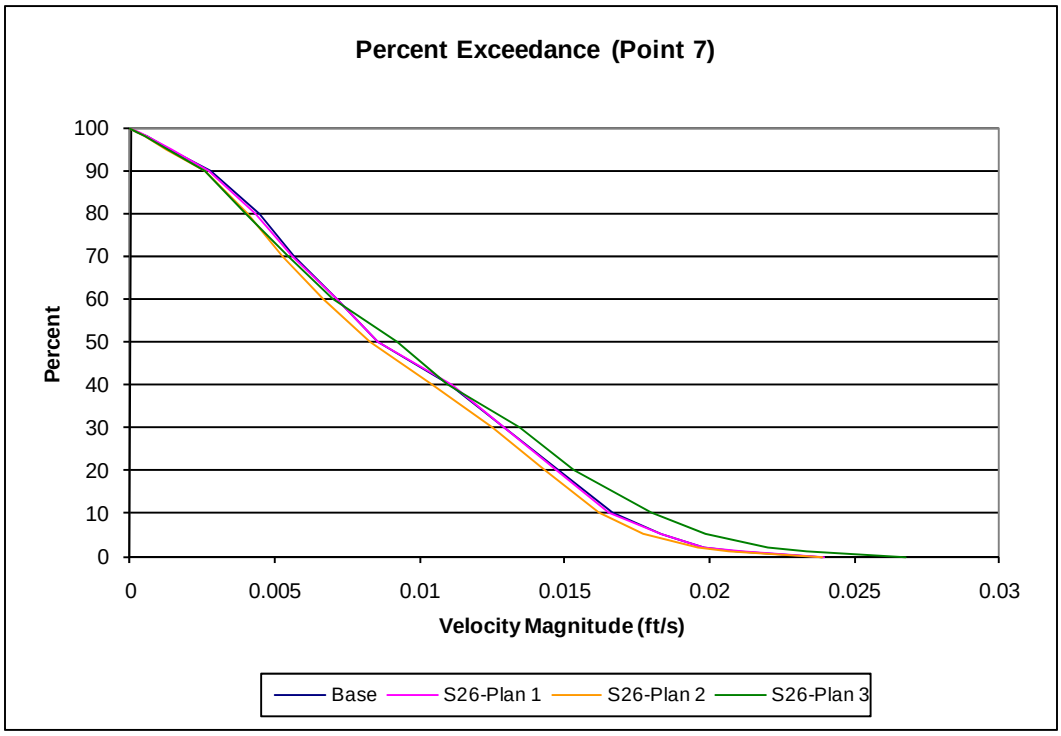

Figure 121. Percent exceedance analysis for point 7 for Station 26 plan set.

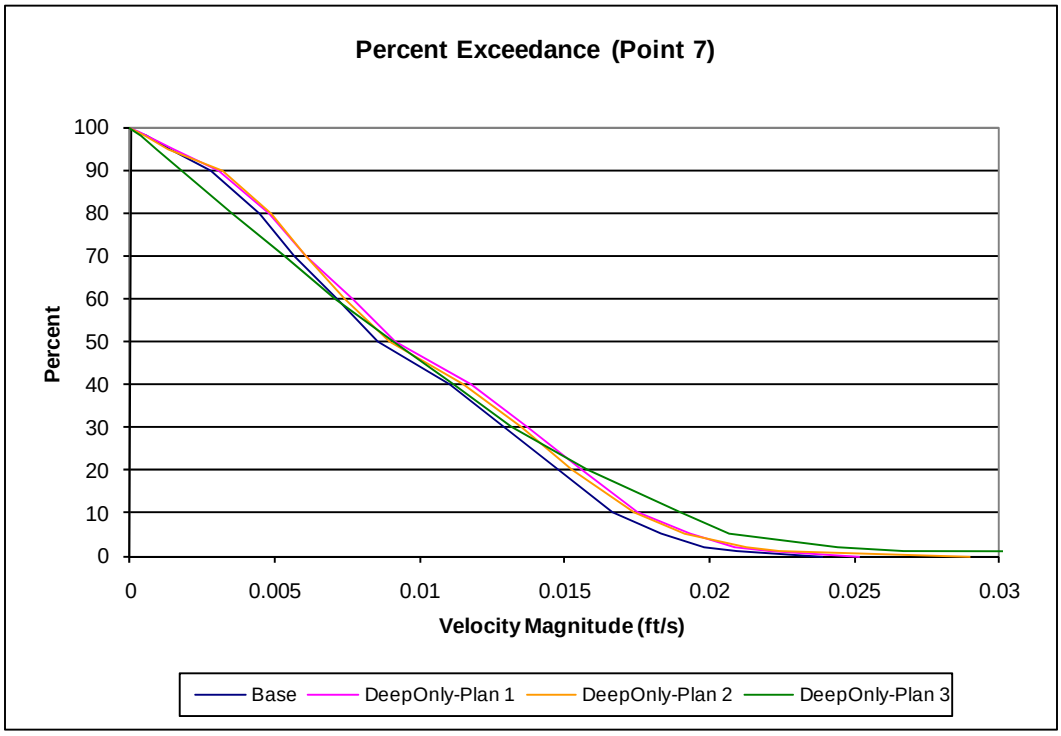

Figure 122. Percent exceedance analysis for point 7 for Deepen Only plan set.

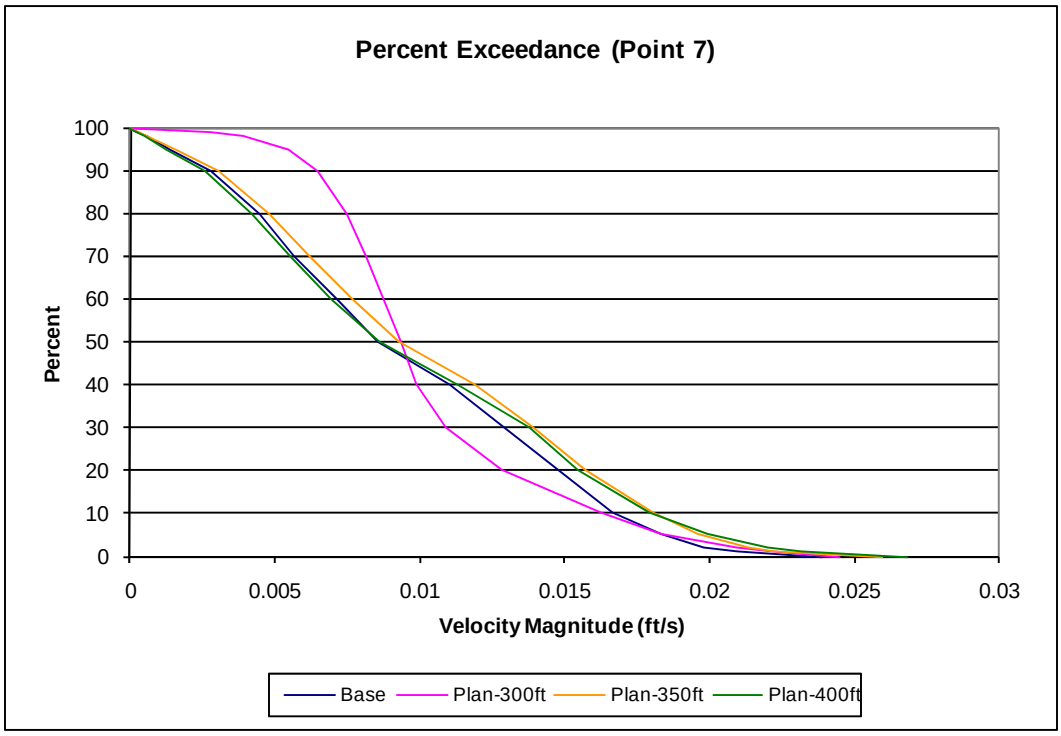

Figure 123. Percent exceedance analysis for point 7 for 300/350/400 plan set.

Figures 124 and 125 are shown to illustrate the reason for the change in direction of the velocity that is indicated in several of the plan conditions. The velocity magnitude and direction for day 15 are shown for a location in the center and at each side of the channel as defined in Figure 29 (see p 30). The Base condition shows that the flows in the center of the channel are directed differently than at the sides. The sides are almost always ebb-directed during this day while the center varies with the tide, but is mostly flood-directed. The Plan 1 velocities indicate that the center and sides are more in sync in terms of direction of flows. The overall flow pattern is the same for the Base and Plan 1, but the wider channel prevents the circulation of the flow over the sides of the channel. If the shallow sides were expanded in proportion to the channel, the velocities would likely maintain the same behavior as the Base condition. The variation of flow direction across the channel explains why the previous velocity figures show large differences in direction from the Base while the discharges remain fairly consistent. The channel cross-sectional flows are very similar in magnitude even if the center has changed flow direction due to the circulation patterns driven by the channel geometry.

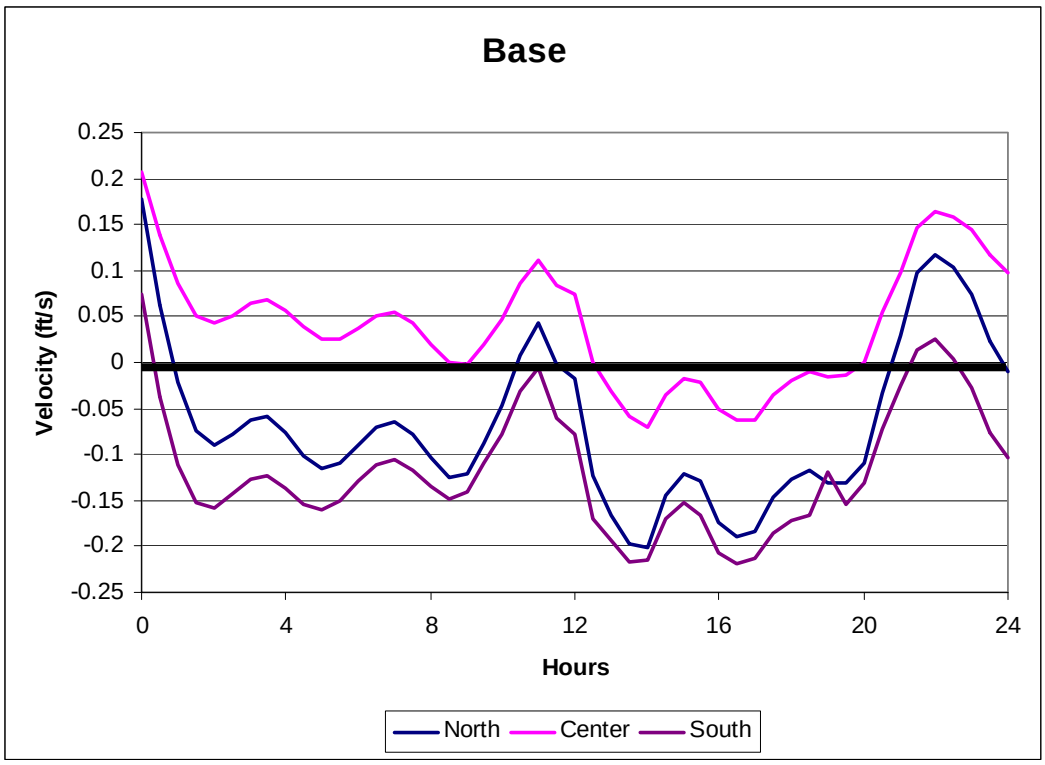

Figure 124. Base velocity magnitude and direction across the channel.

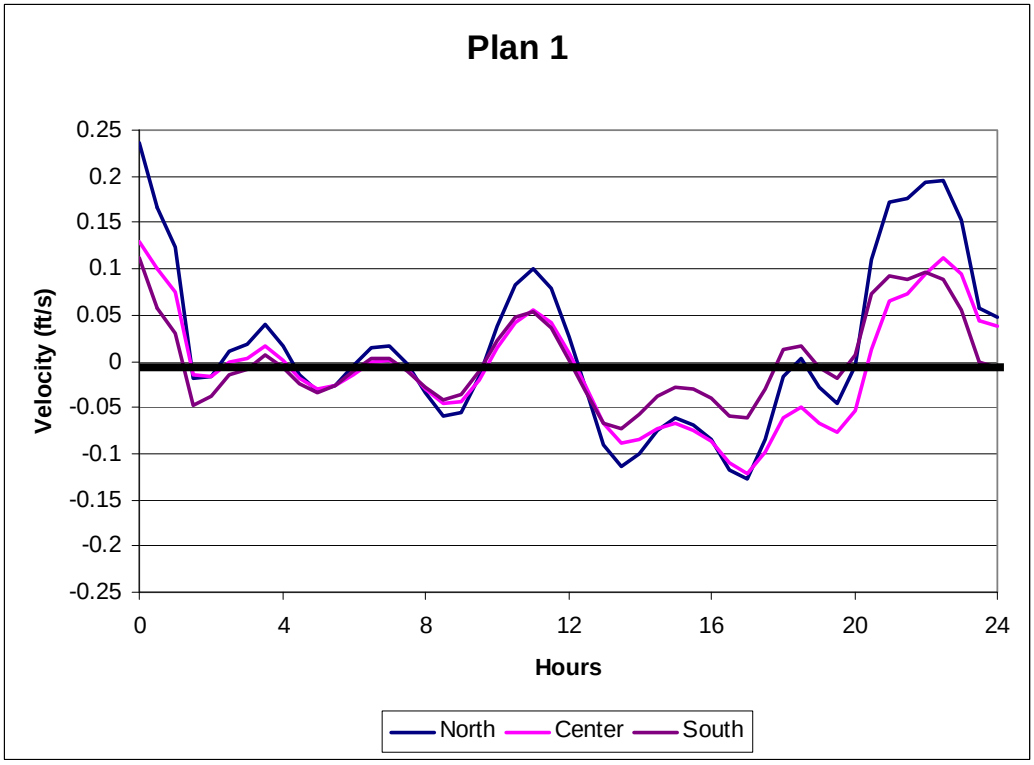

Figure 125. Initial-Plan 1 velocity magnitude and direction across the channel.

4.2.3 Water surface elevation comparisons

Water surface elevation comparisons are shown in Figures 126 – 229 for all analysis locations on day 15 and day 29, again referenced to MLLW. There are small differences in the water surface elevation in the channel due to the widening and deepening. These differences are larger for the day 29 results than day 15, and the greatest differences are seen during a falling elevation. This result agrees with the velocity results in that the day 29 variation from the Base condition is greater than the day 15 variation. These differences increase slightly with each deepening, although each change is quite small. Overall, the effect of the change in channel dimensions does not affect the water surface elevations in the study area in a way that would impact navigation.

Farther away from the ship channel in the Laguna Madre, the effects of the changes in the channel become negligible (Figures 182 – 229). Only at points 8 and 9, which are near the channel, are water surface elevation changes seen that compare with those in the channel.

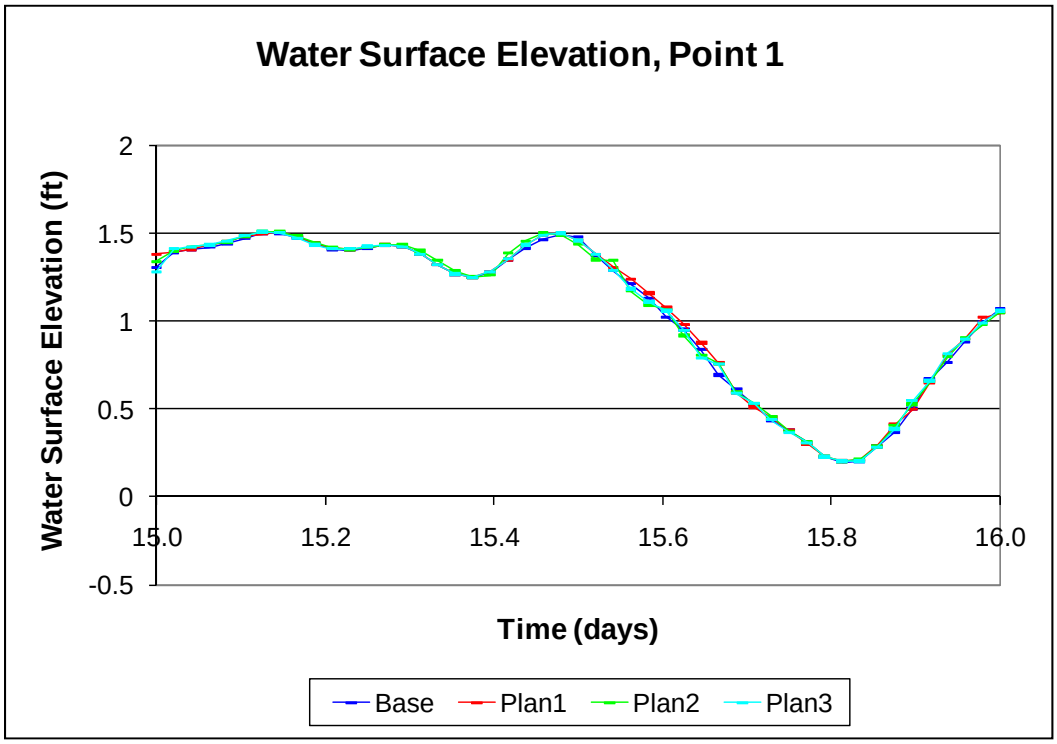

Figure 126. Water surface comparison for day 15 at point 1 for Initial plan set.

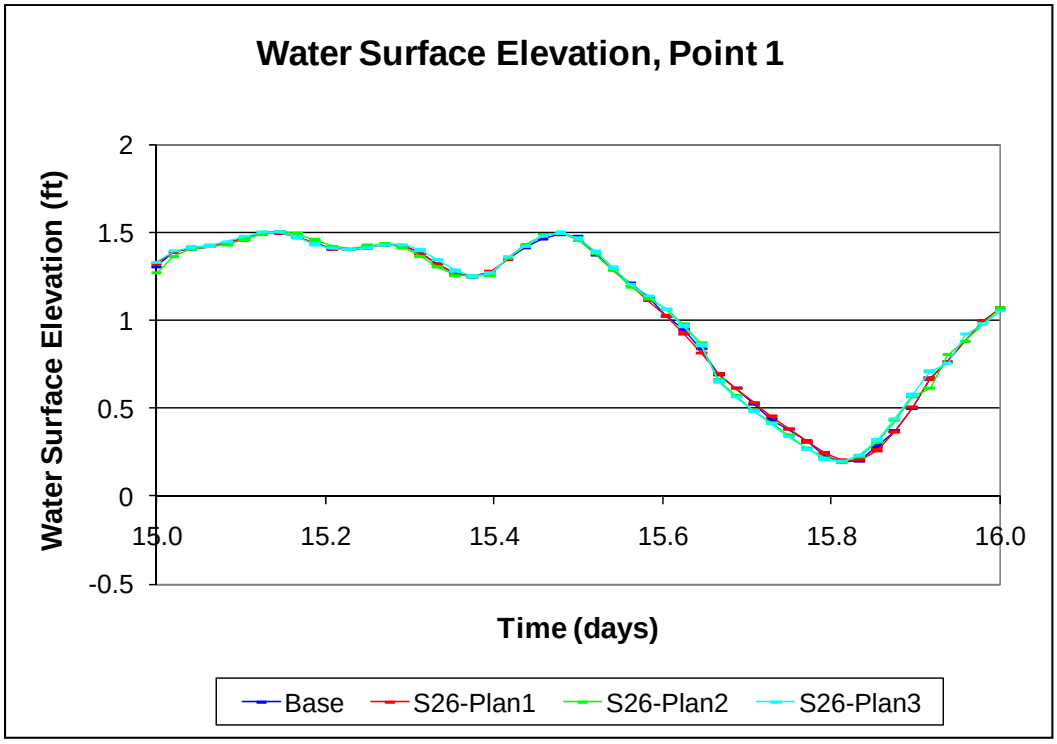

Figure 127. Water surface comparison for day 15 at point 1 for Station 26 plan set.

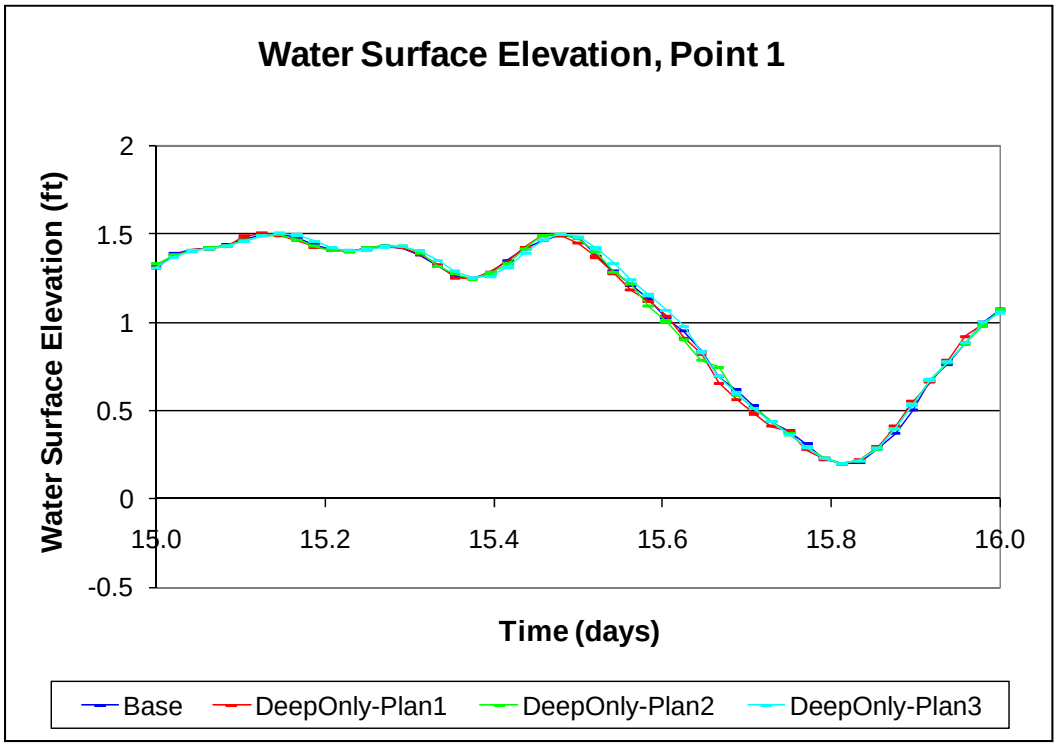

Figure 128. Water surface comparison for day 15 at point 1 for Deepen Only plan set.

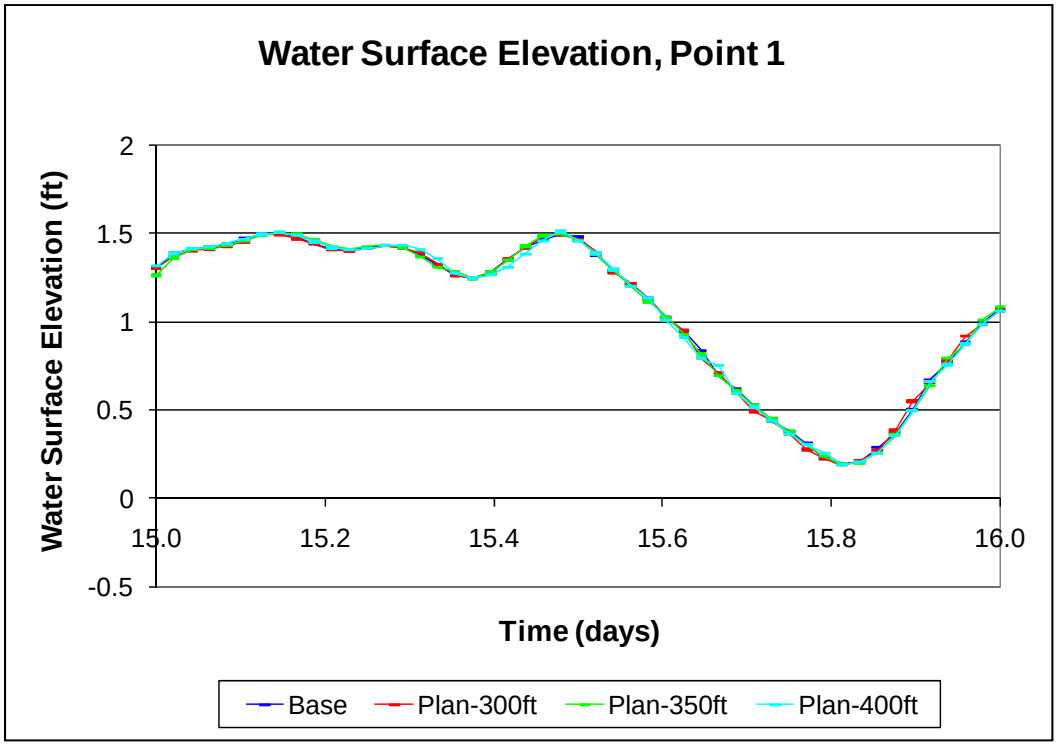

Figure 129. Water surface comparison for day 15 at point 1 for 300/350/400 plan set.

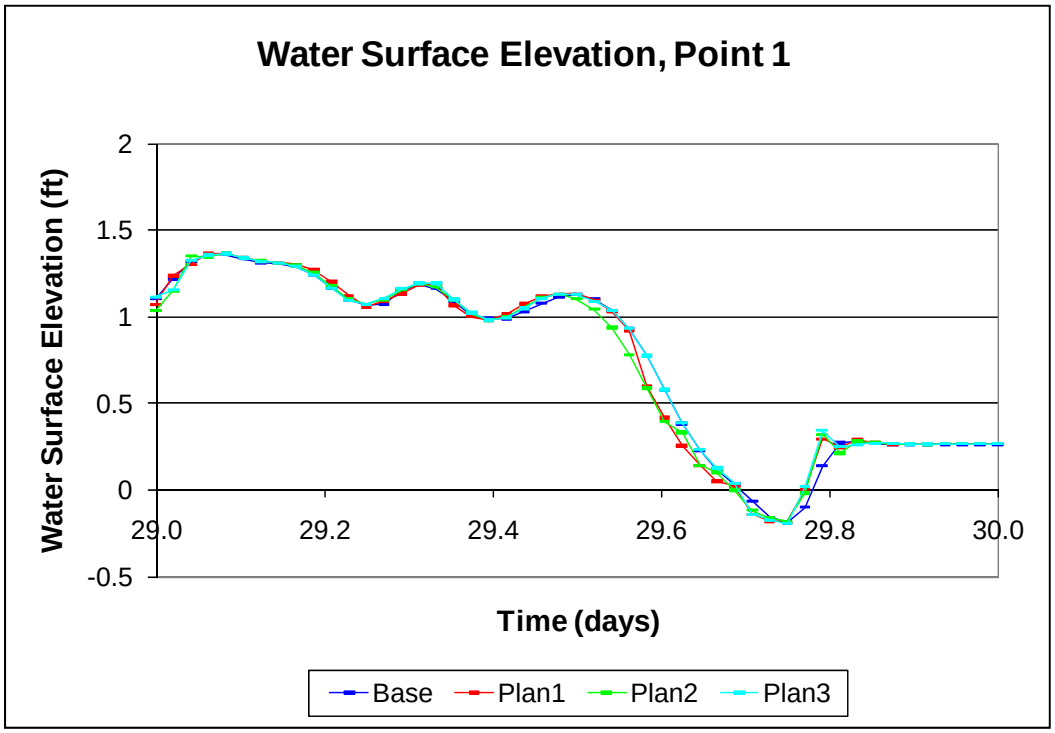

Figure 130. Water surface comparison for day 29 at point 1 for Initial plan set.

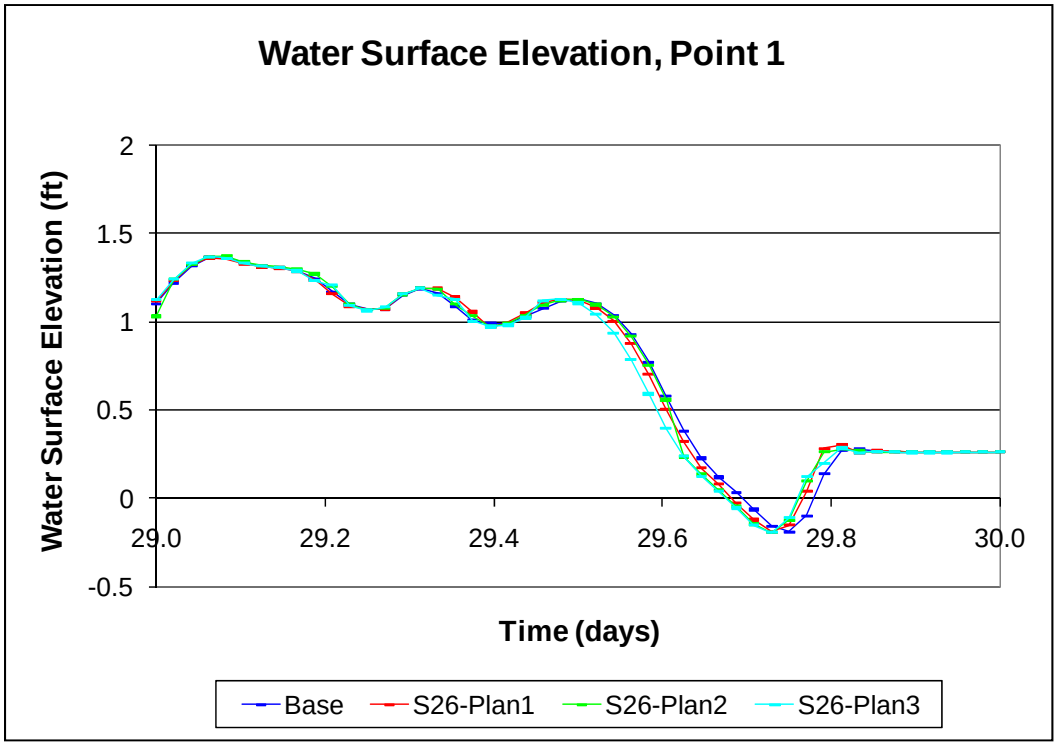

Figure 131. Water surface comparison for day 29 at point 1 for Station 26 plan set.

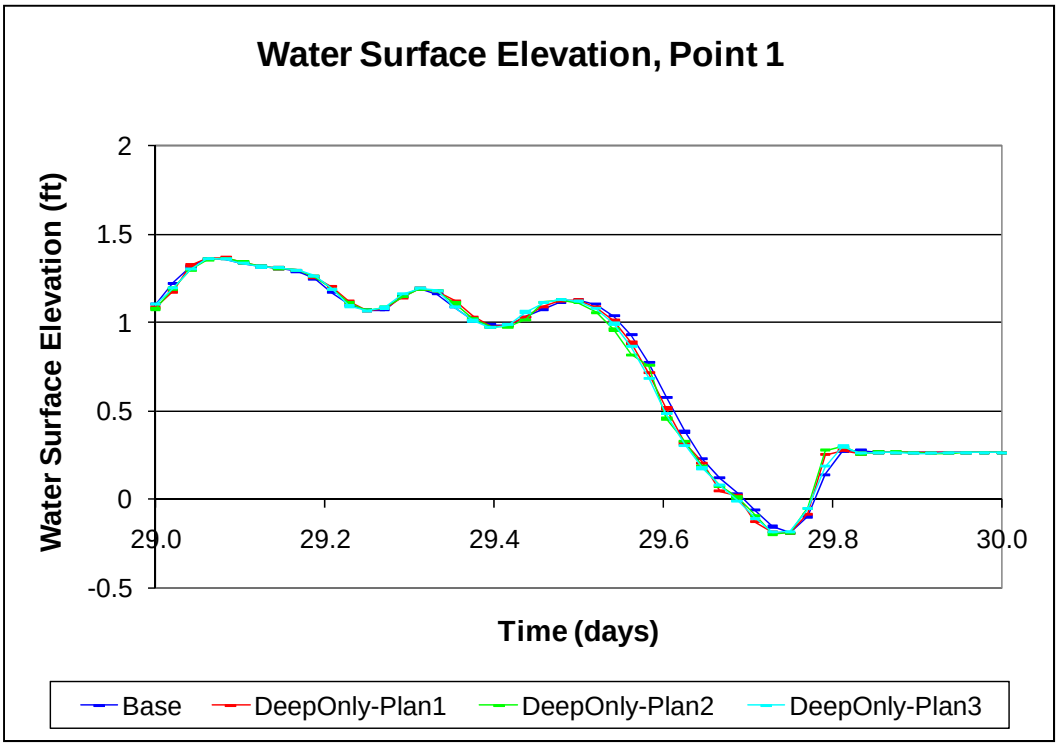

Figure 132. Water surface comparison for day 29 at point 1 for Deepen Only plan set.

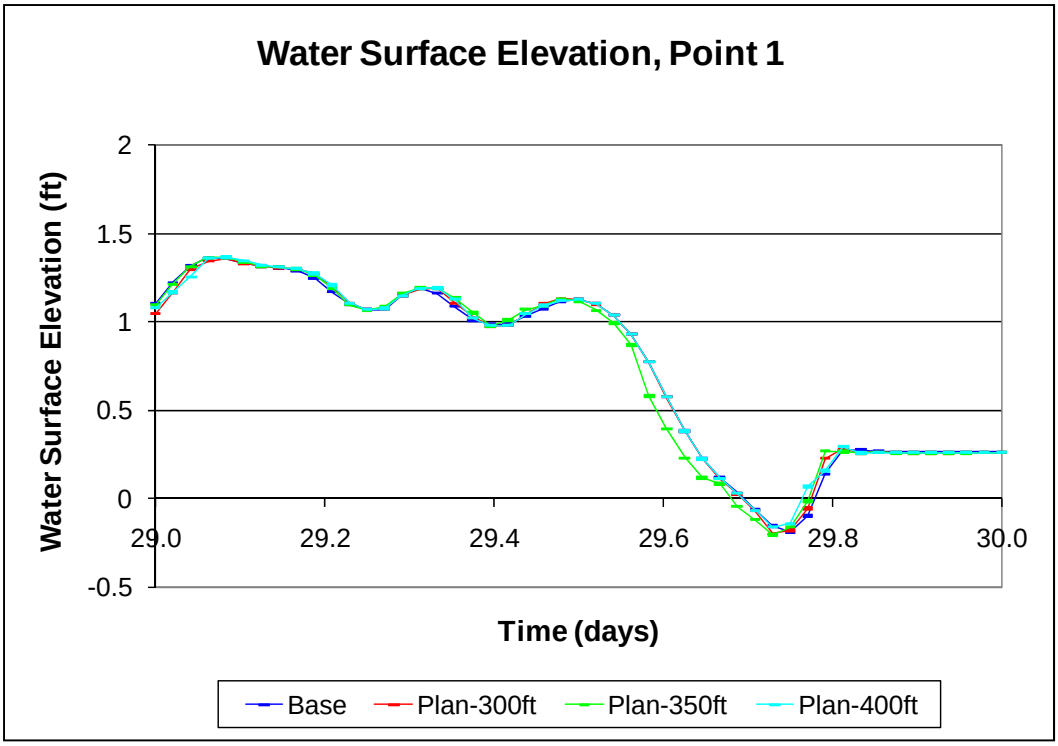

Figure 133. Water surface comparison for day 29 at point 1 for 300/350/400 plan set.

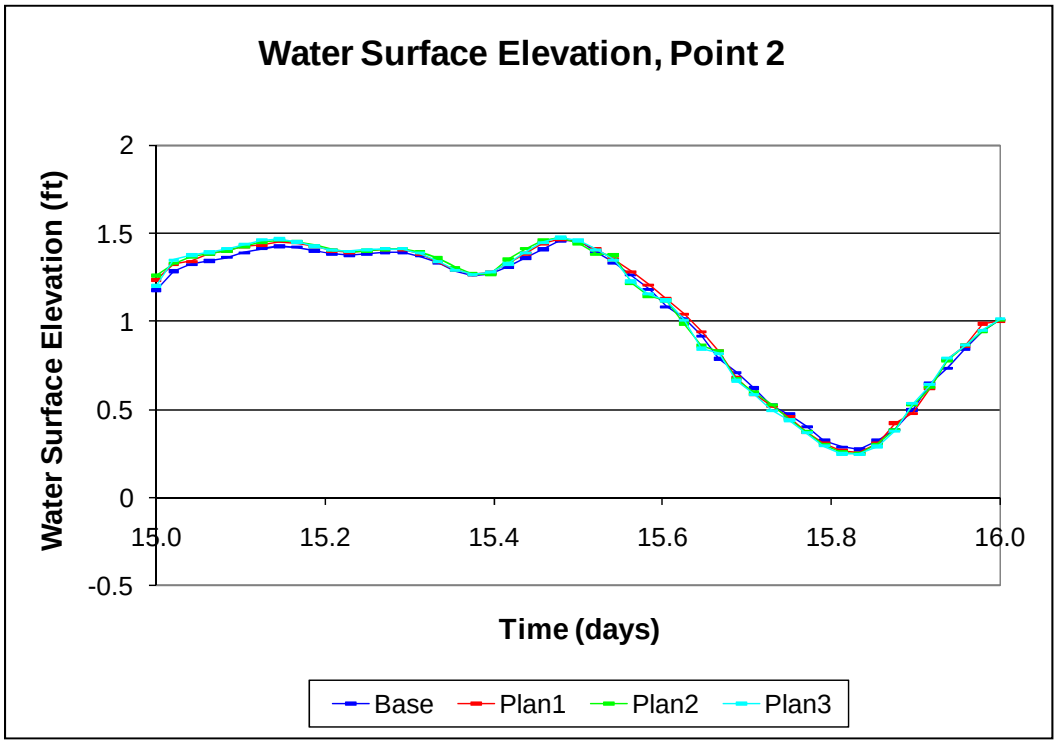

Figure 134. Water surface comparison for day 15 at point 2 for Initial plan set.

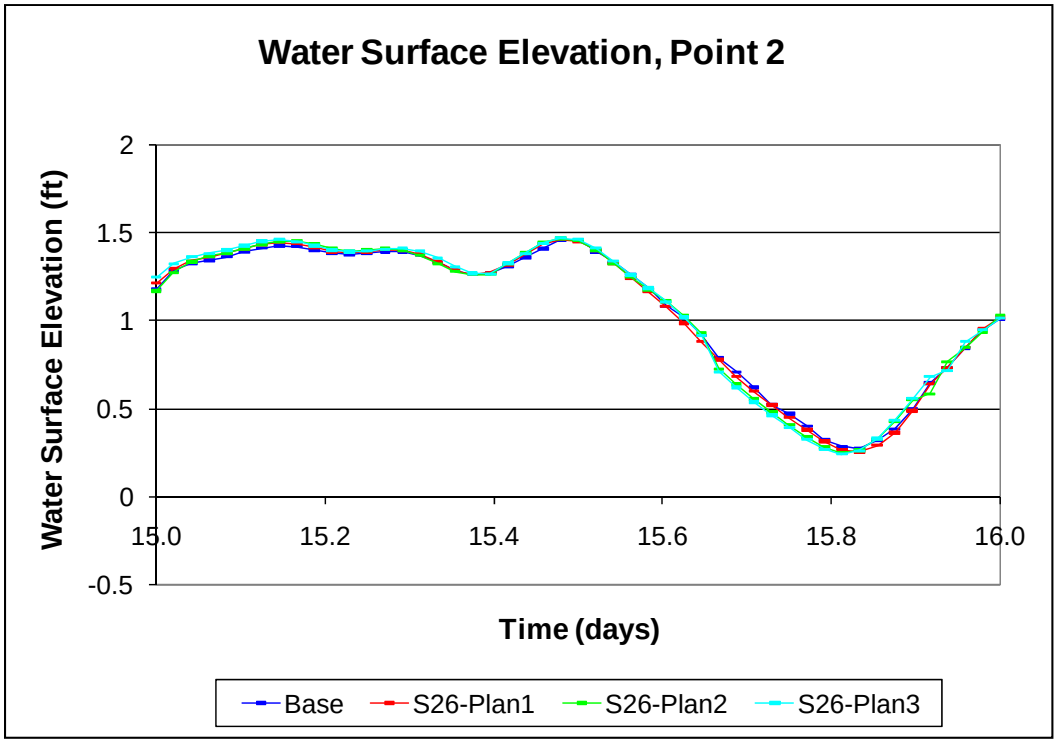

Figure 135. Water surface comparison for day 15 at point 2 for Station 26 plan set.

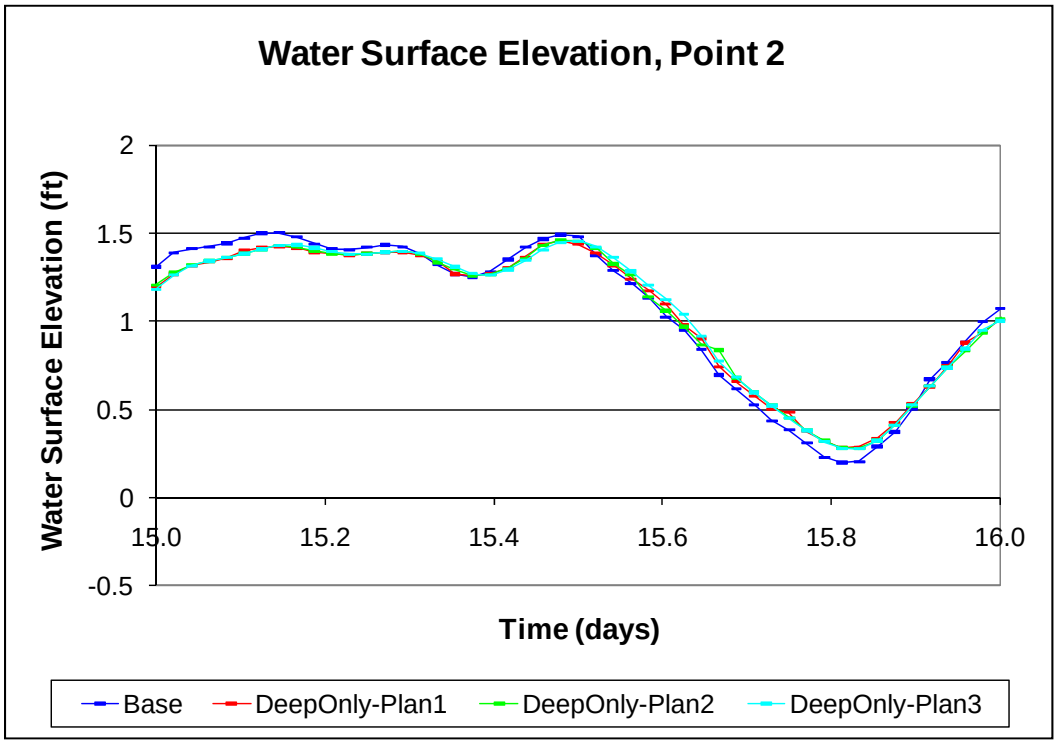

Figure 136. Water surface comparison for day 15 at point 2 for Deepen Only plan set.

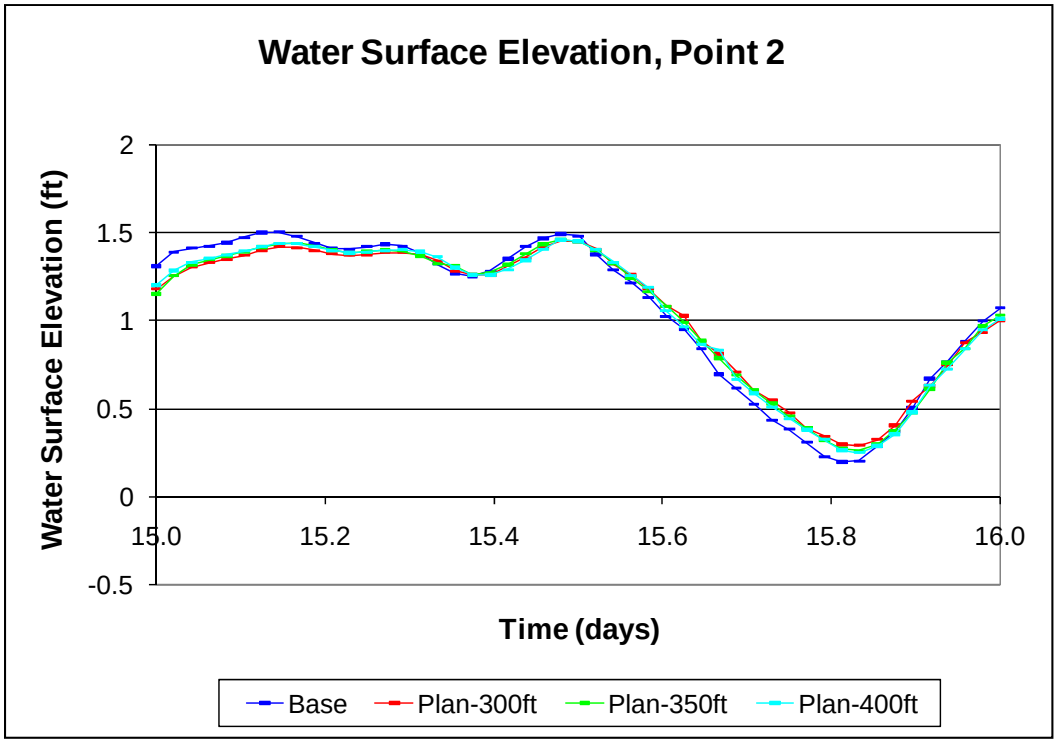

Figure 137. Water surface comparison for day 15 at point 2 for 300/350/400 plan set.

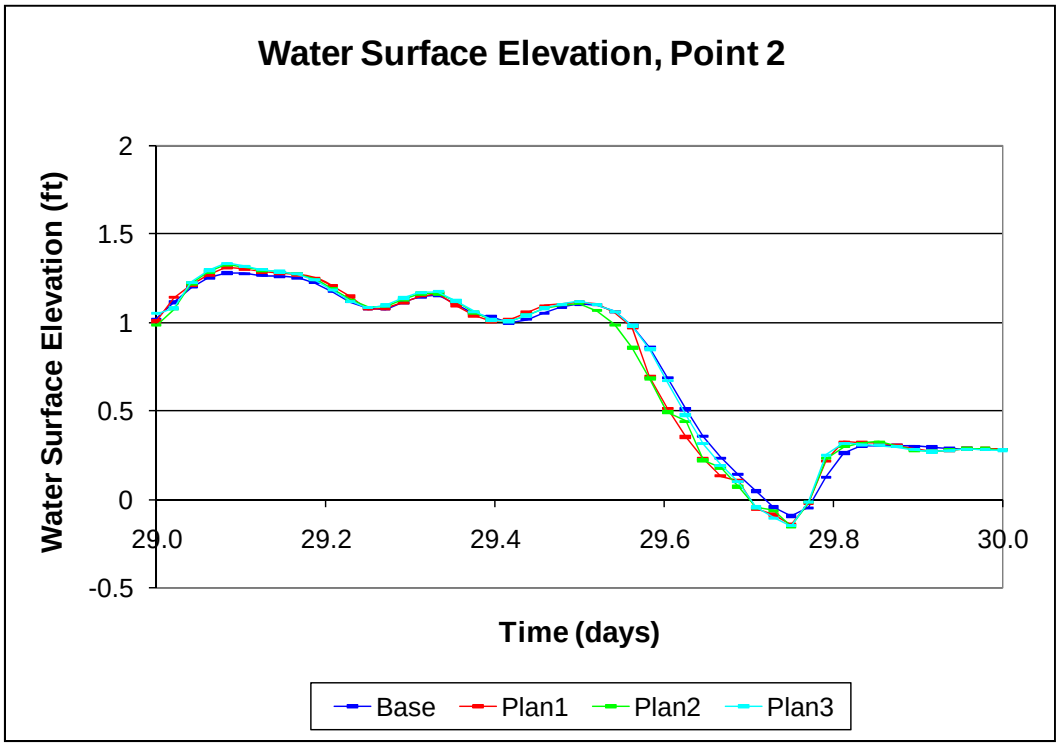

Figure 138. Water surface comparison for day 29 at point 2 for Initial plan set.

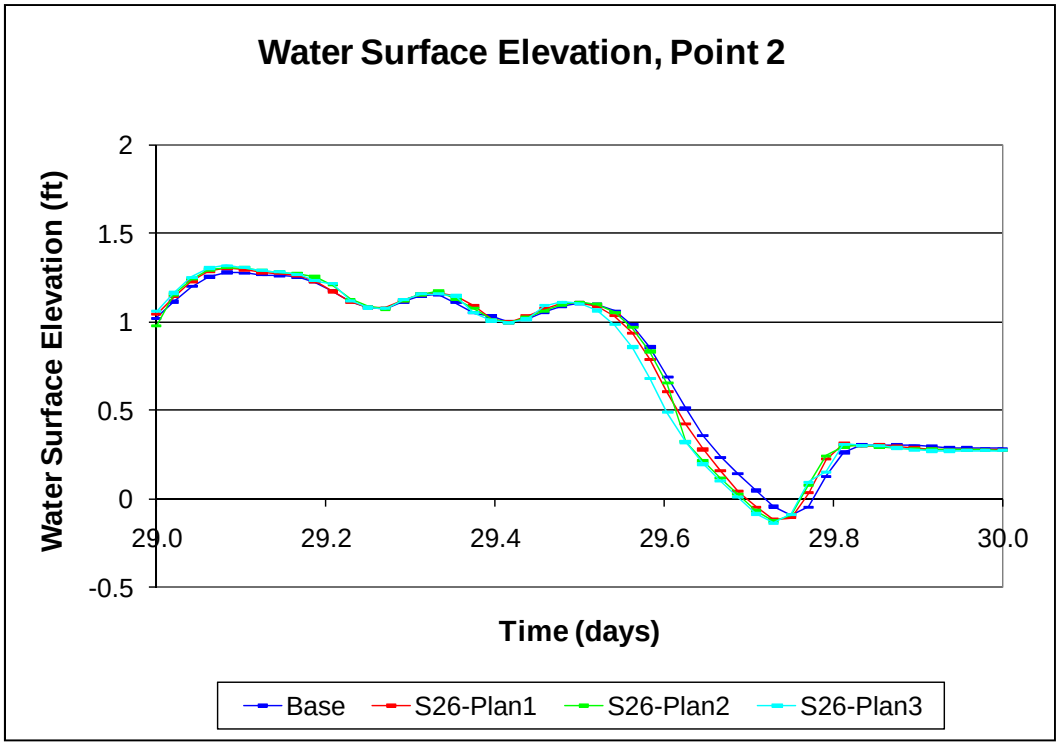

Figure 139. Water surface comparison for day 29 at point 2 for Station 26 plan set.

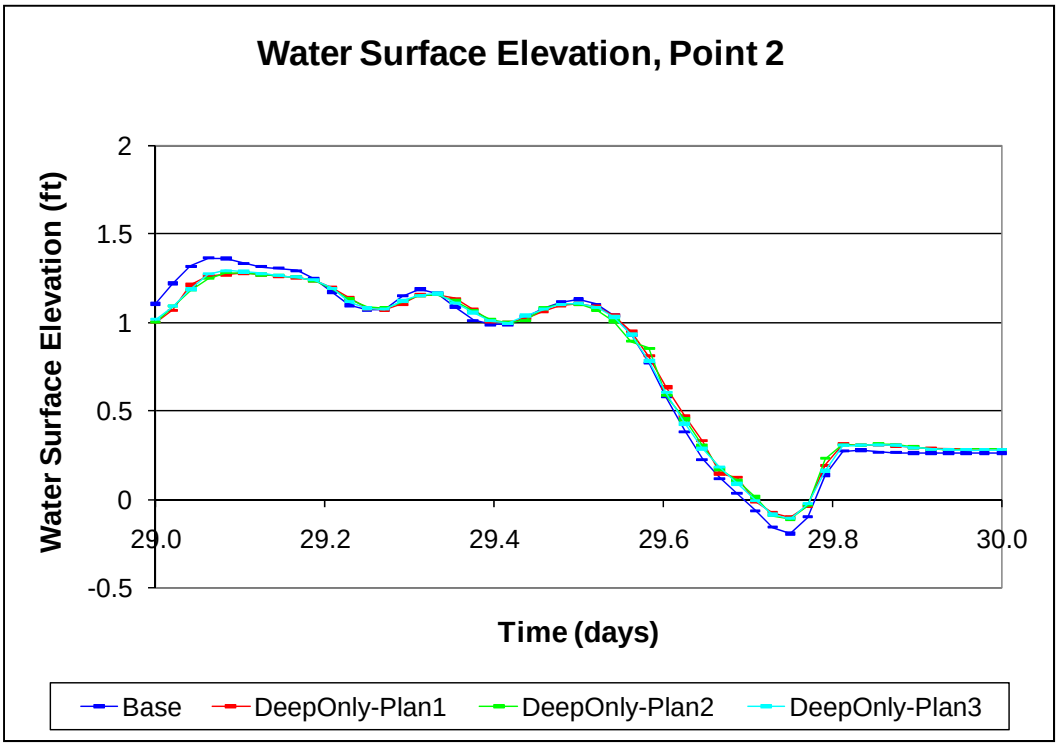

Figure 140. Water surface comparison for day 29 at point 2 for Deepen Only plan set.

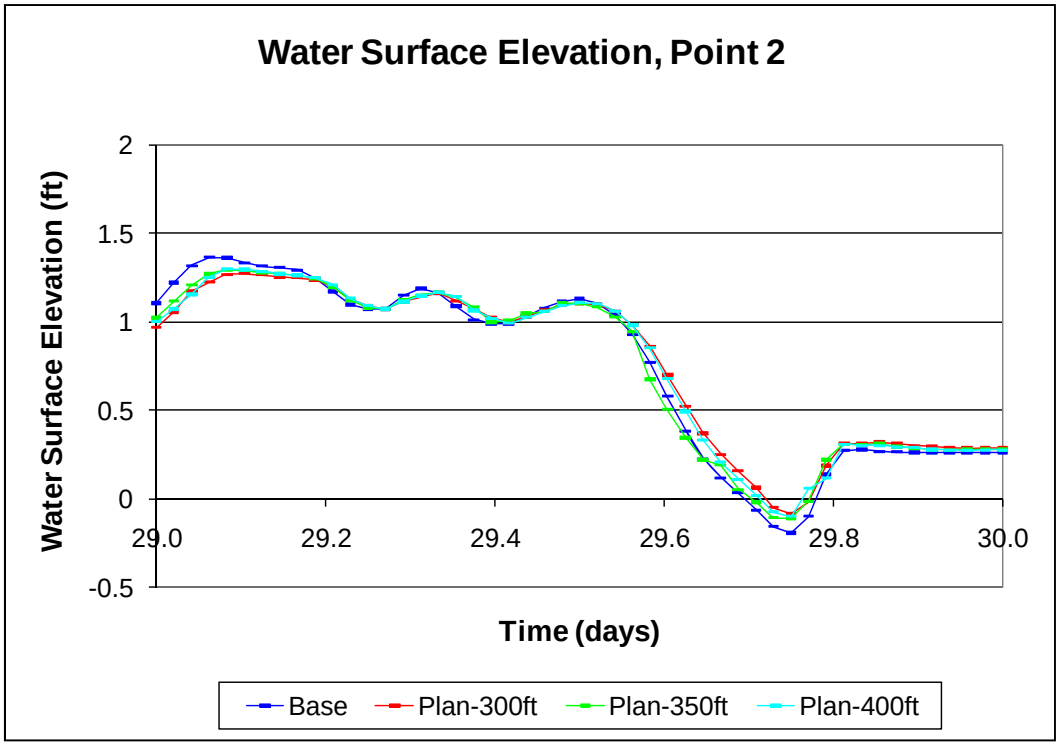

Figure 141. Water surface comparison for day 29 at point 2 for 300/350/400 plan set.

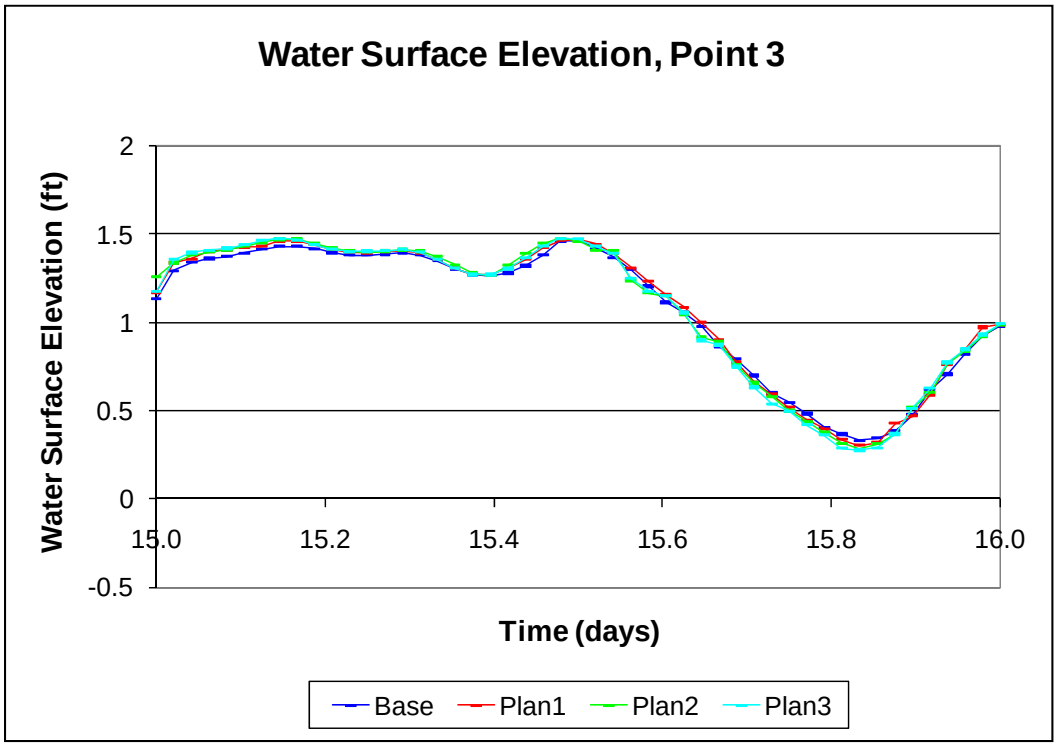

Figure 142. Water surface comparison for day 15 at point 3 for Initial plan set.

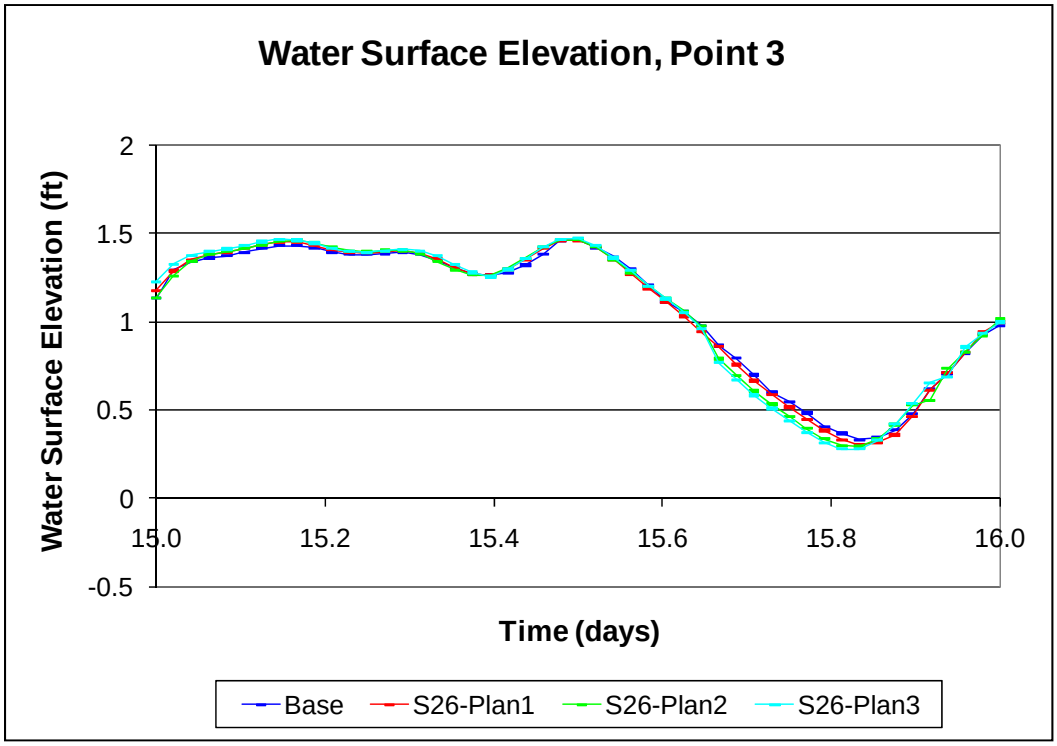

Figure 143. Water surface comparison for day 15 at point 3 for Station 26 plan set.

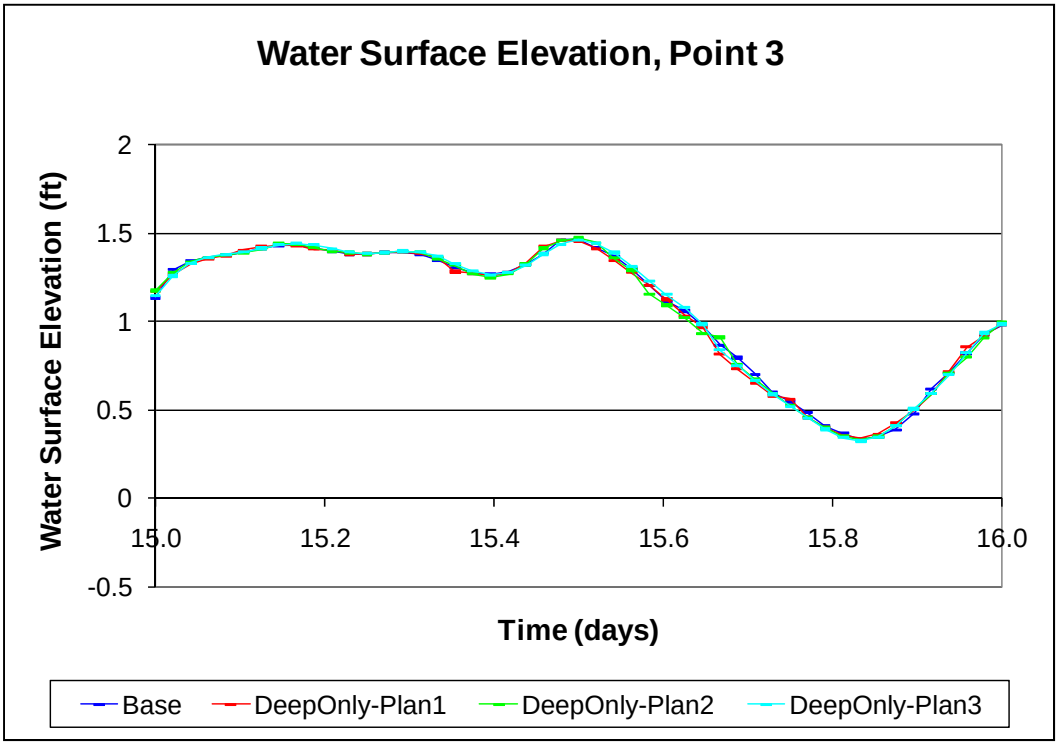

Figure 144. Water surface comparison for day 15 at point 3 for Deepen Only plan set.

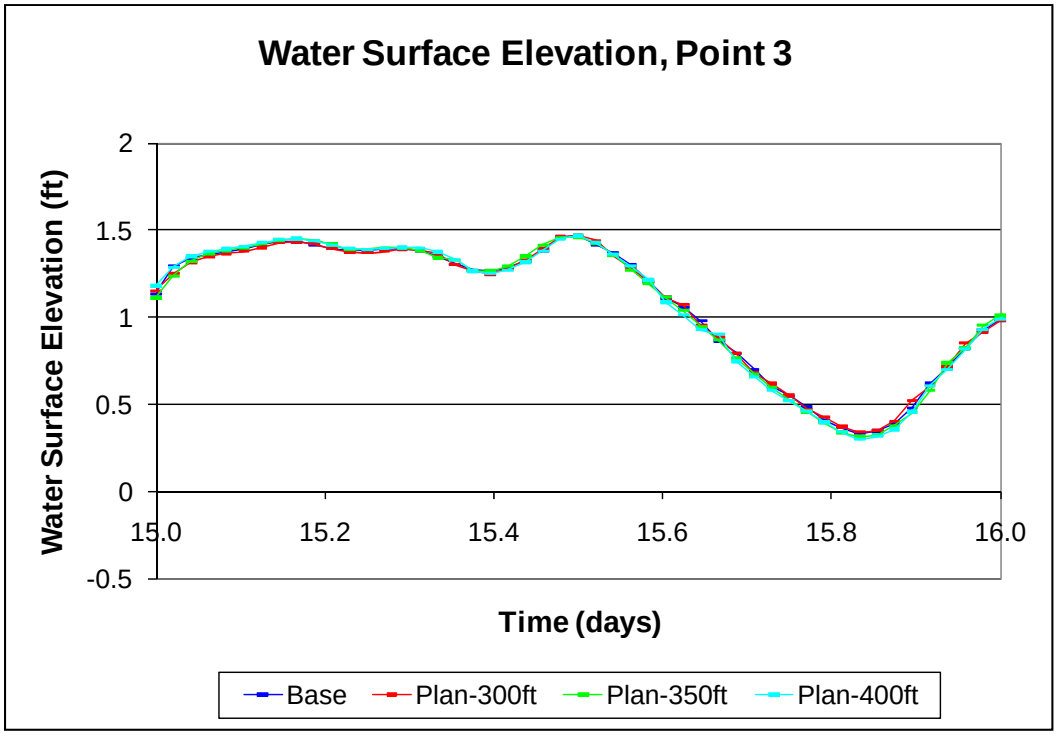

Figure 145. Water surface comparison for day 15 at point 3 for 300/350/400 plan set.

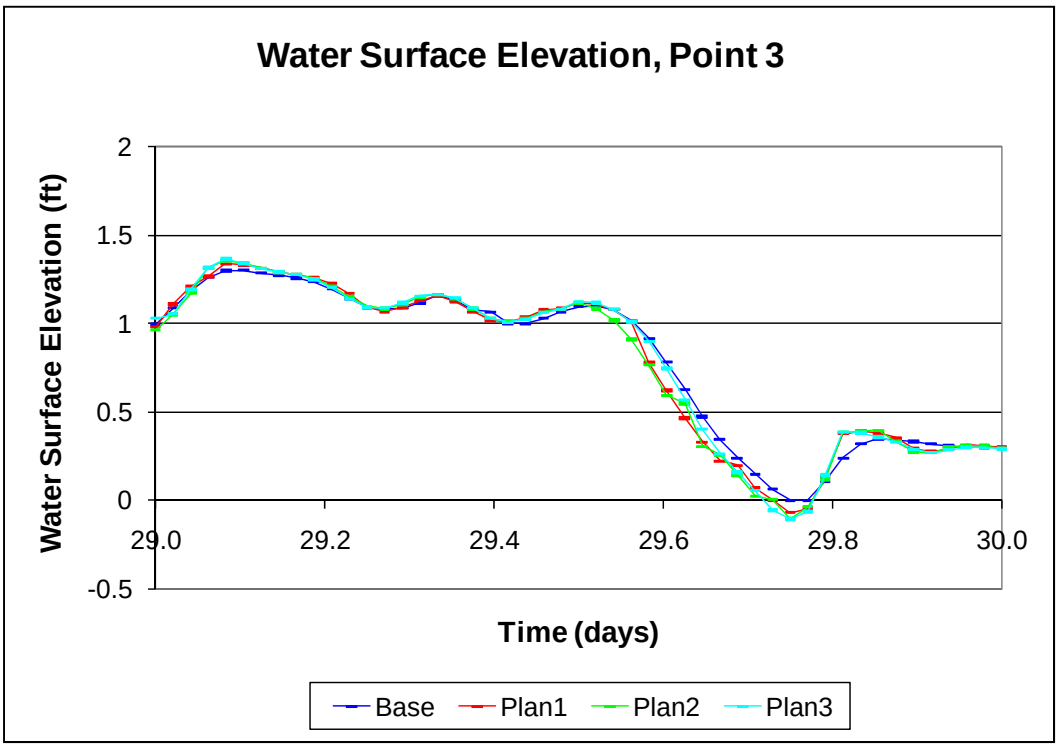

Figure 146. Water surface comparison for day 29 at point 3 for Initial plan set.

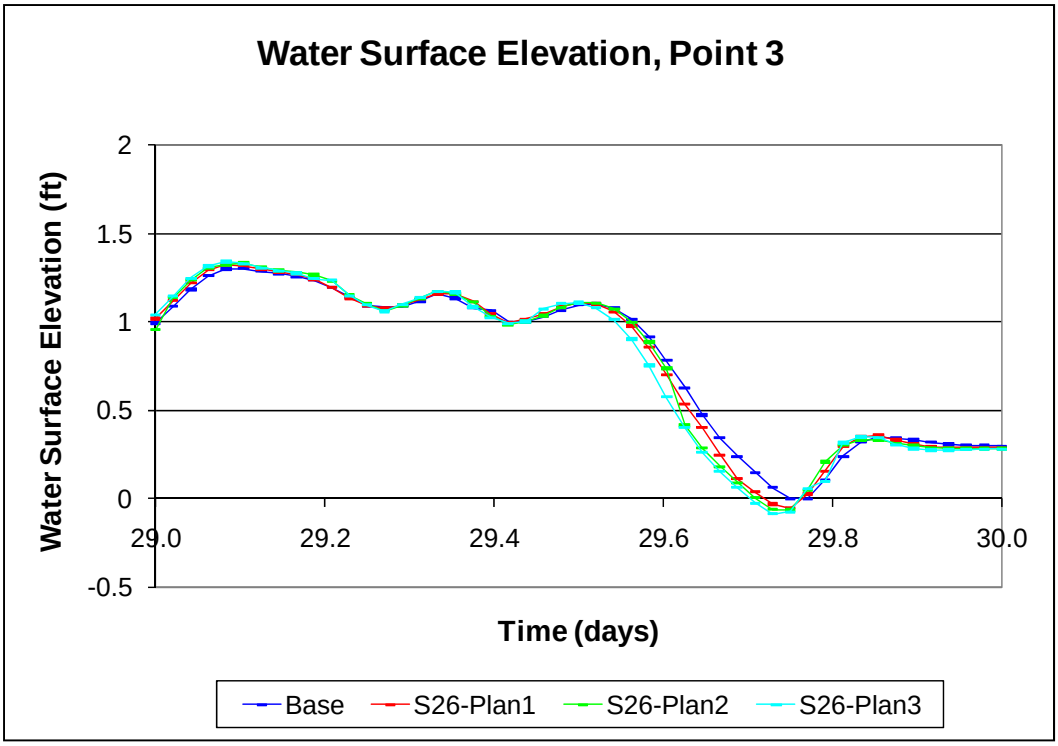

Figure 147. Water surface comparison for day 29 at point 3 for Station 26 plan set.

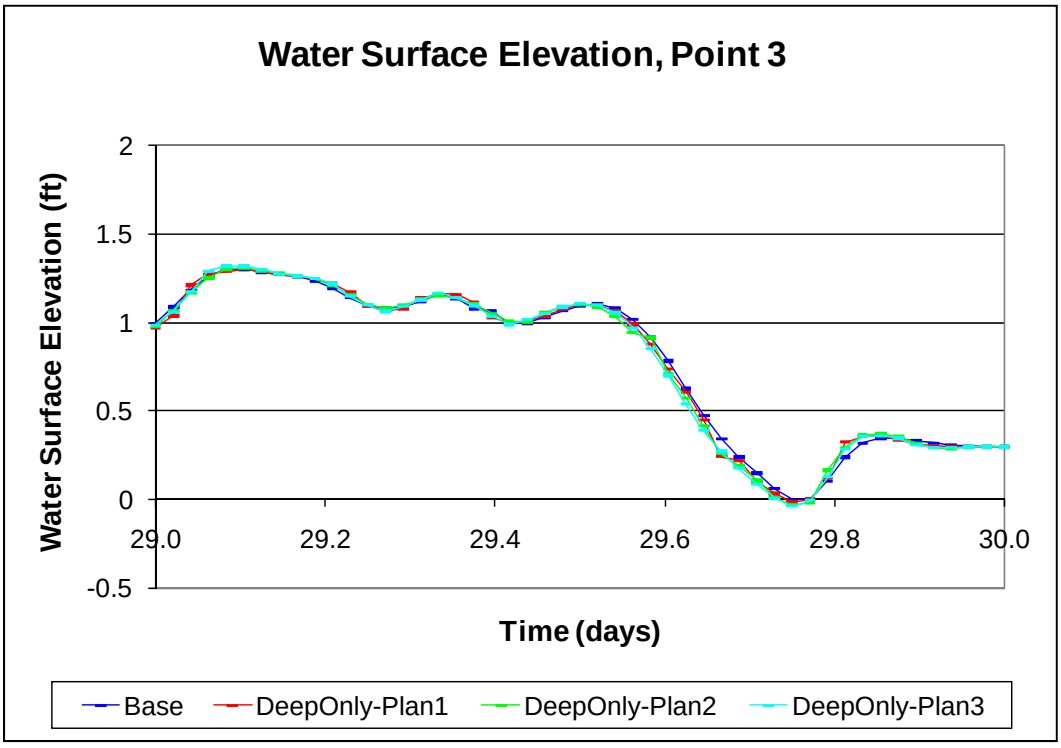

Figure 148. Water surface comparison for day 29 at point 3 for Deepen Only plan set.

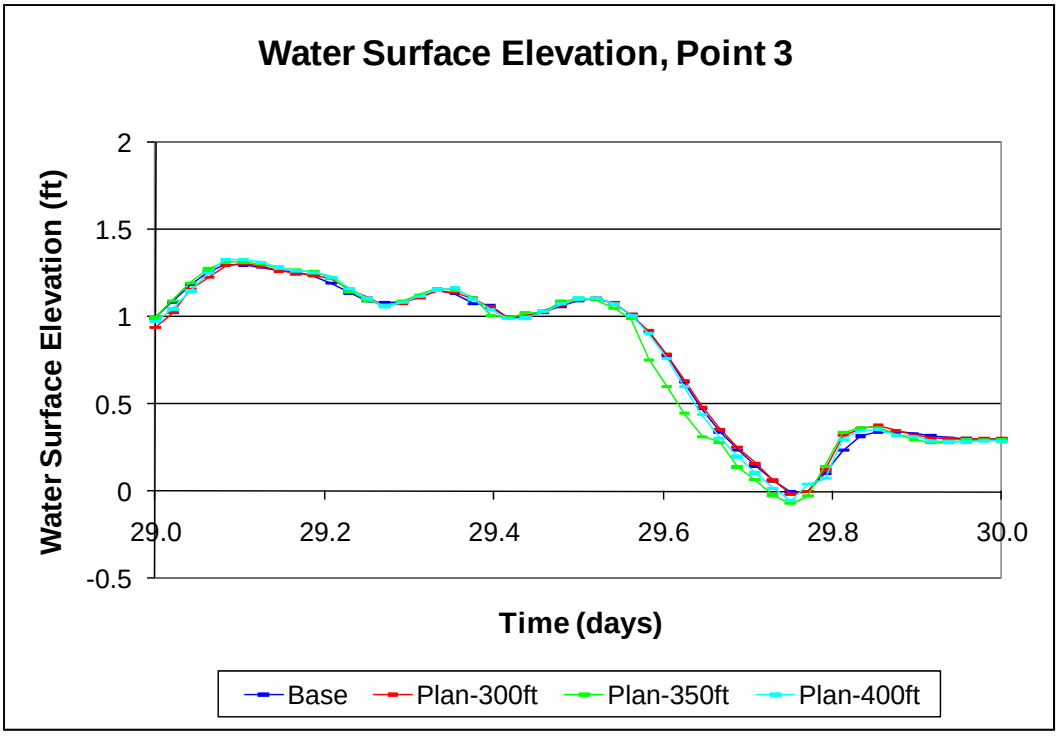

Figure 149. Water surface comparison for day 29 at point 3 for 300/350/400 plan set.

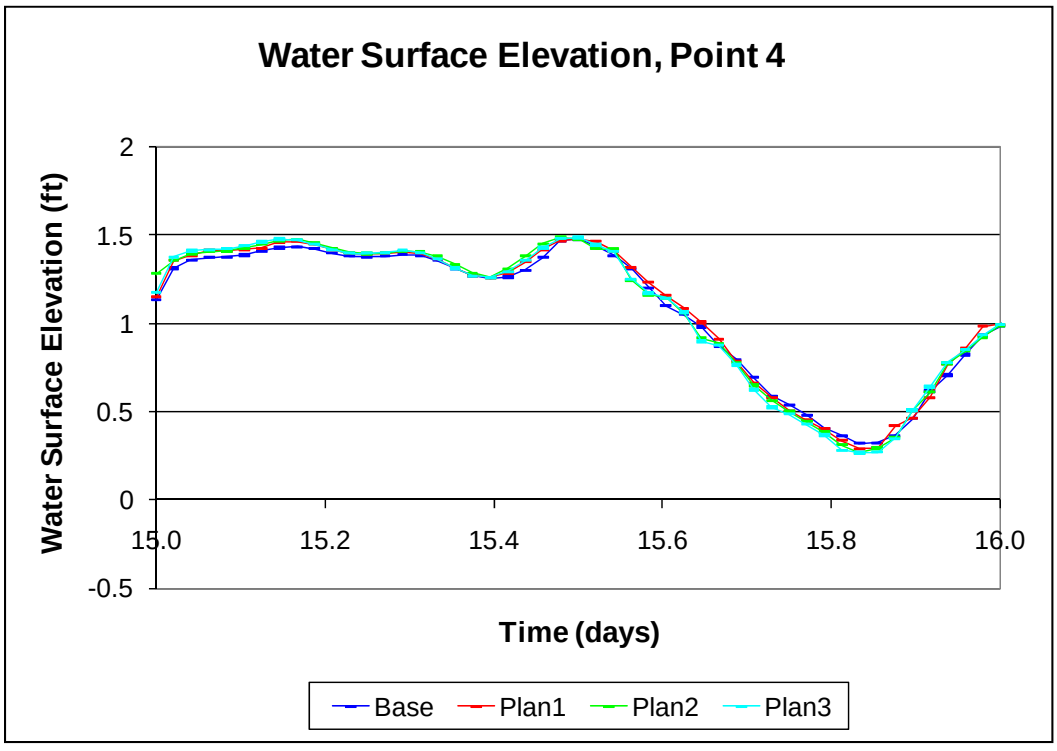

Figure 150. Water surface comparison for day 15 at point 4 for Initial plan set.

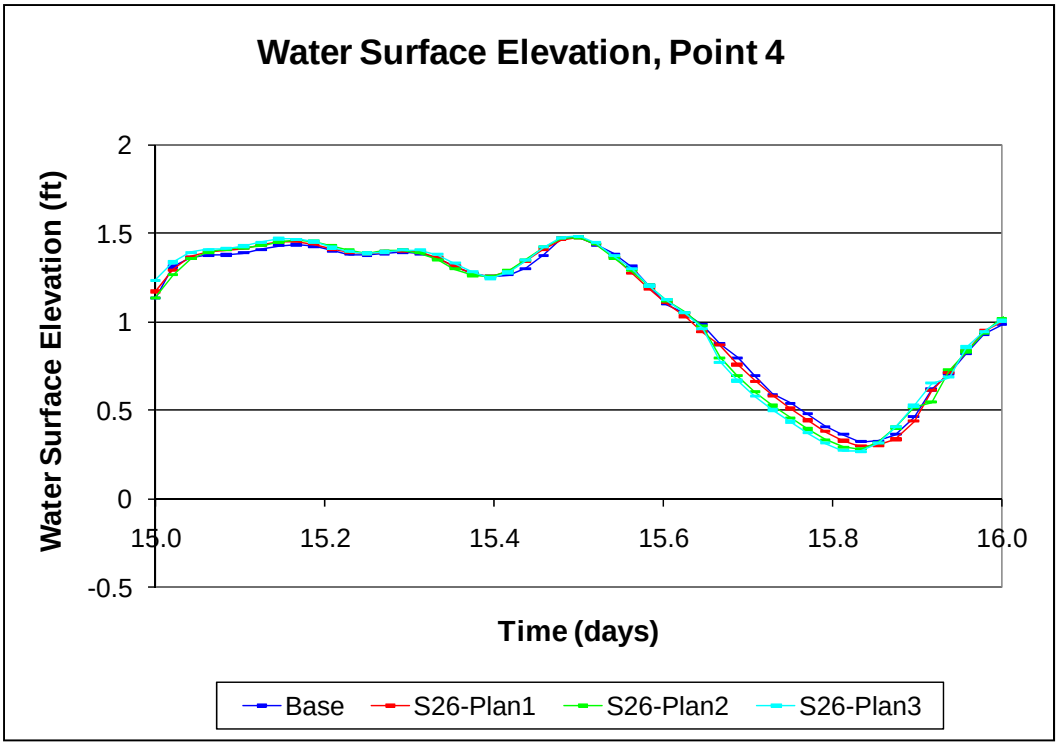

Figure 151. Water surface comparison for day 15 at point 4 for Station 26 plan set.

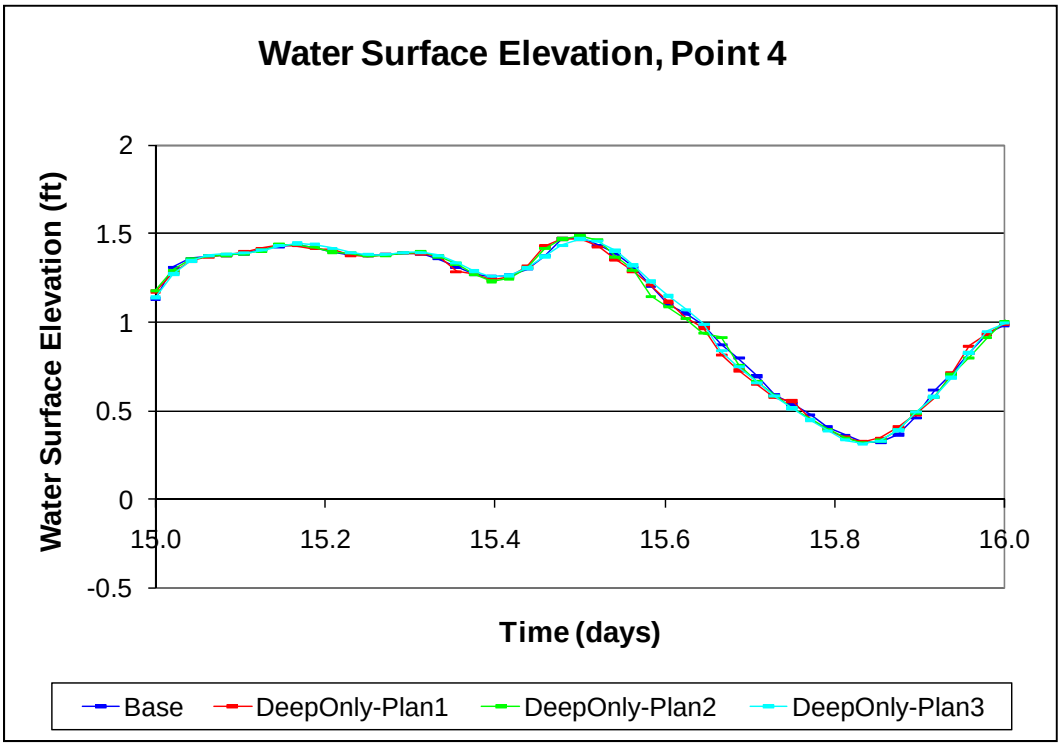

Figure 152. Water surface comparison for day 15 at point 4 for Deepen Only plan set.

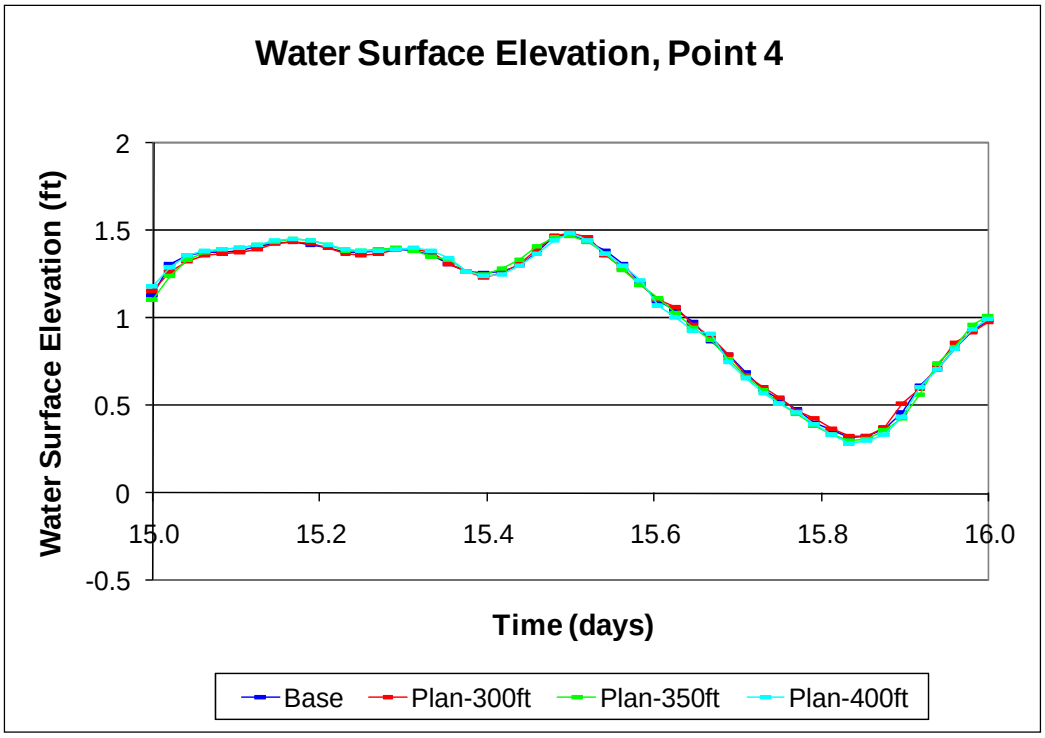

Figure 153. Water surface comparison for day 15 at point 4 for 300/350/400 plan set.

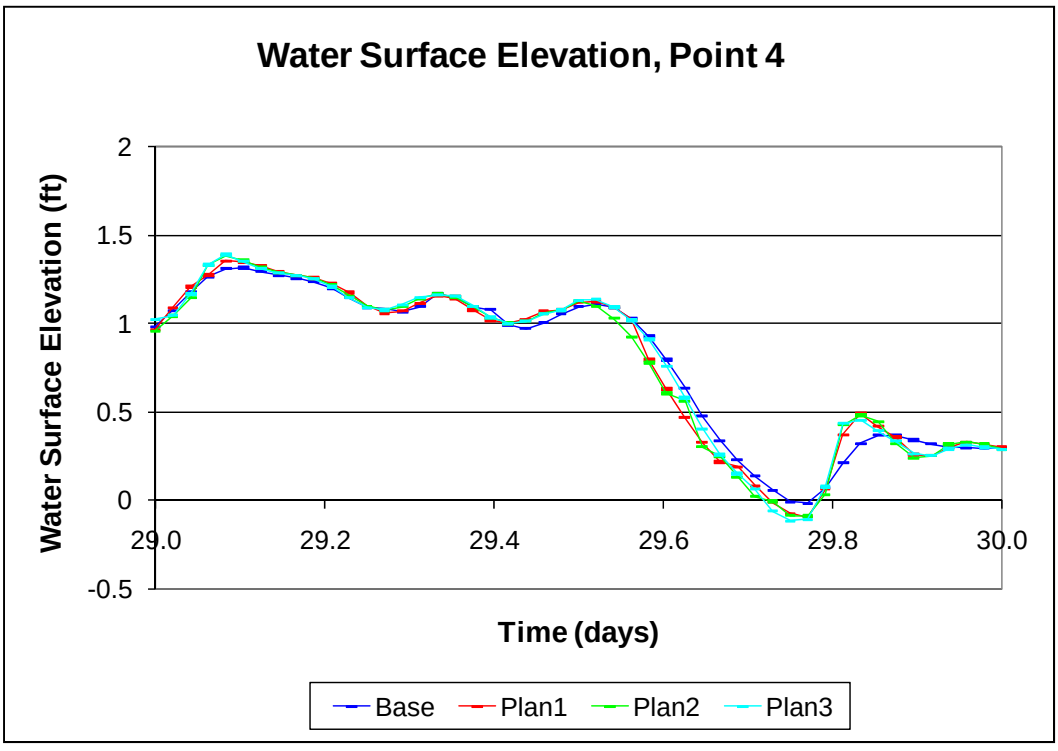

Figure 154. Water surface comparison for day 29 at point 4 for Initial plan set.

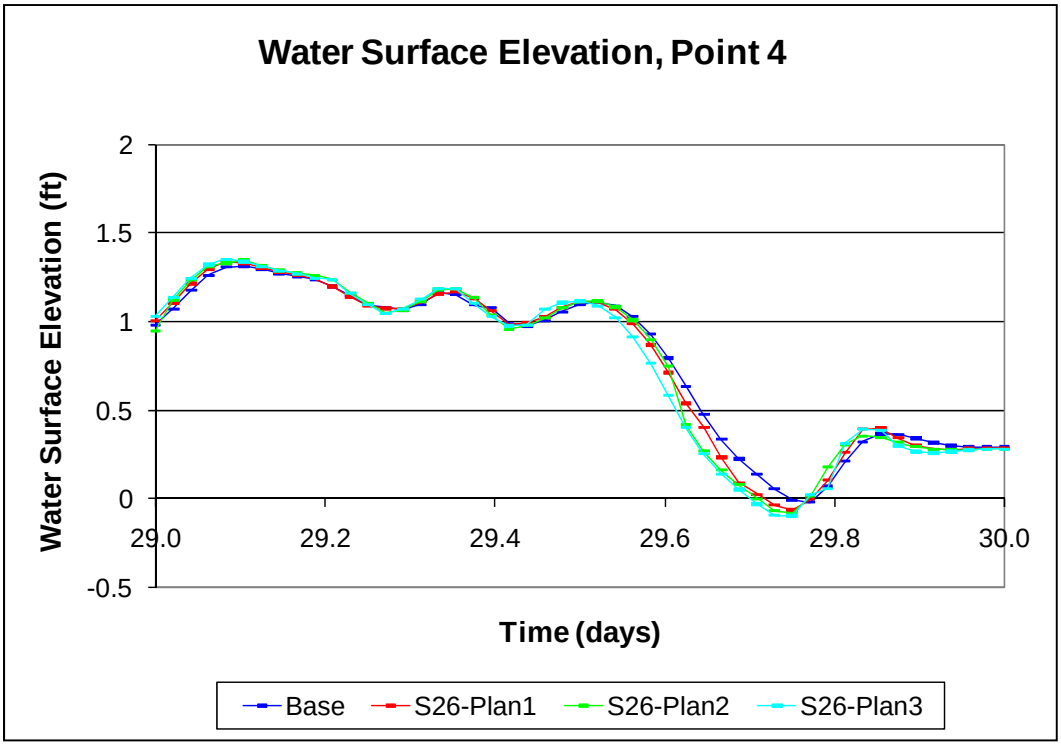

Figure 155. Water surface comparison for day 29 at point 4 for Station 26 plan set.

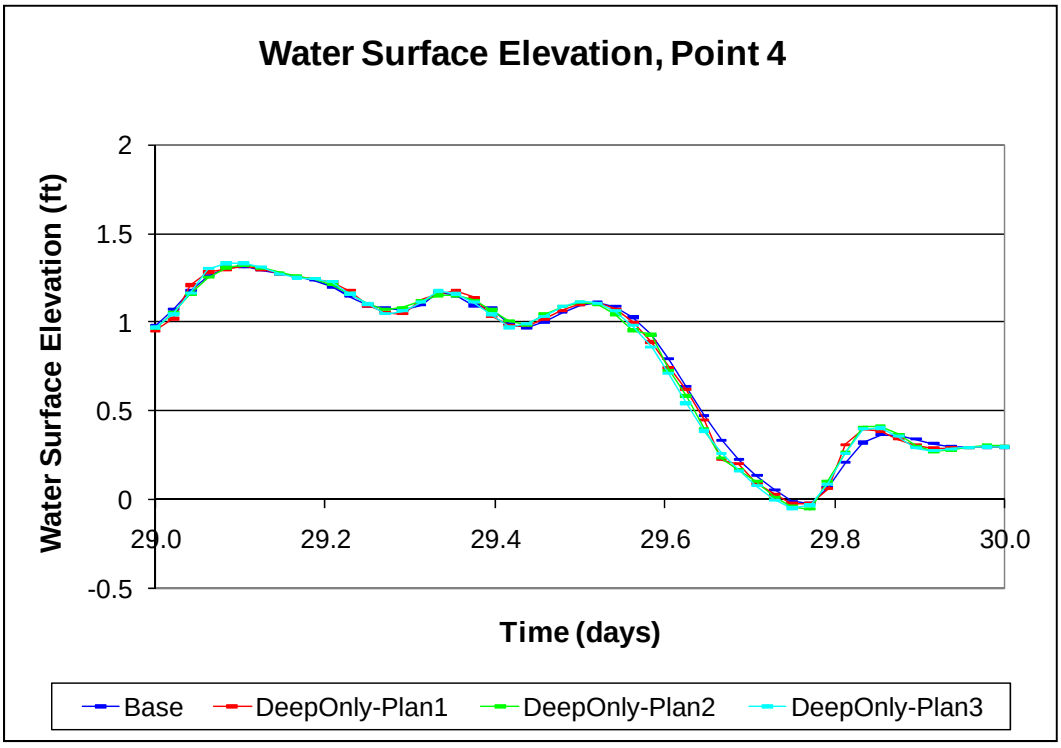

Figure 156. Water surface comparison for day 29 at point 4 for Deepen Only plan set.

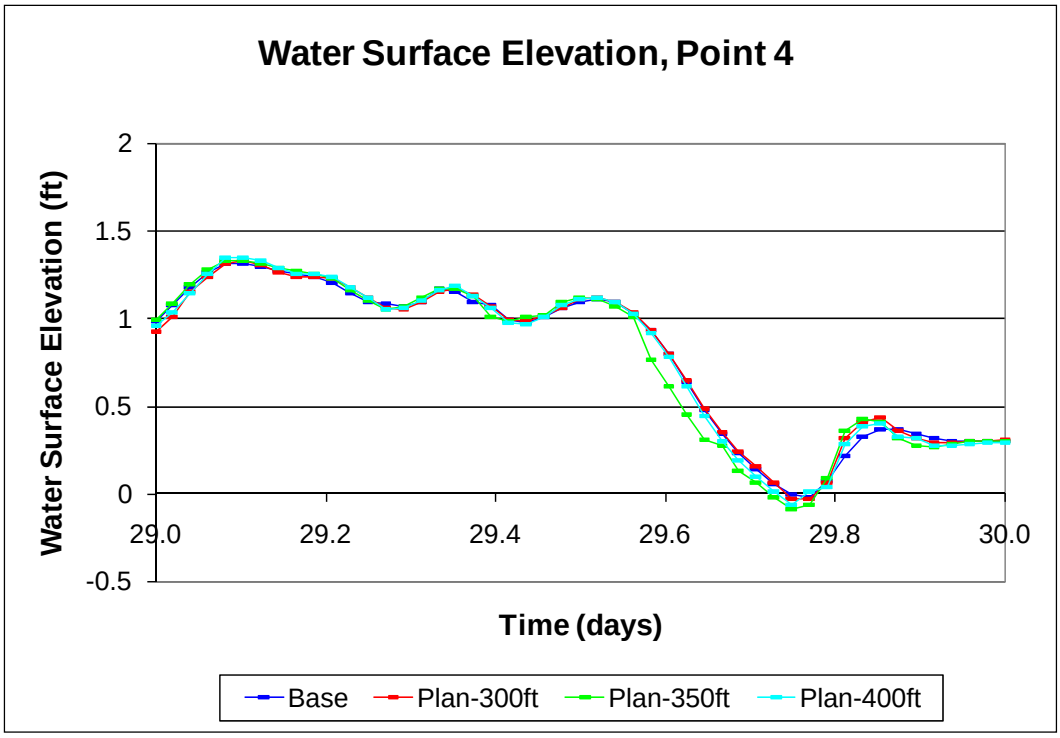

Figure 157. Water surface comparison for day 29 at point 4 for 300/350/400 plan set.

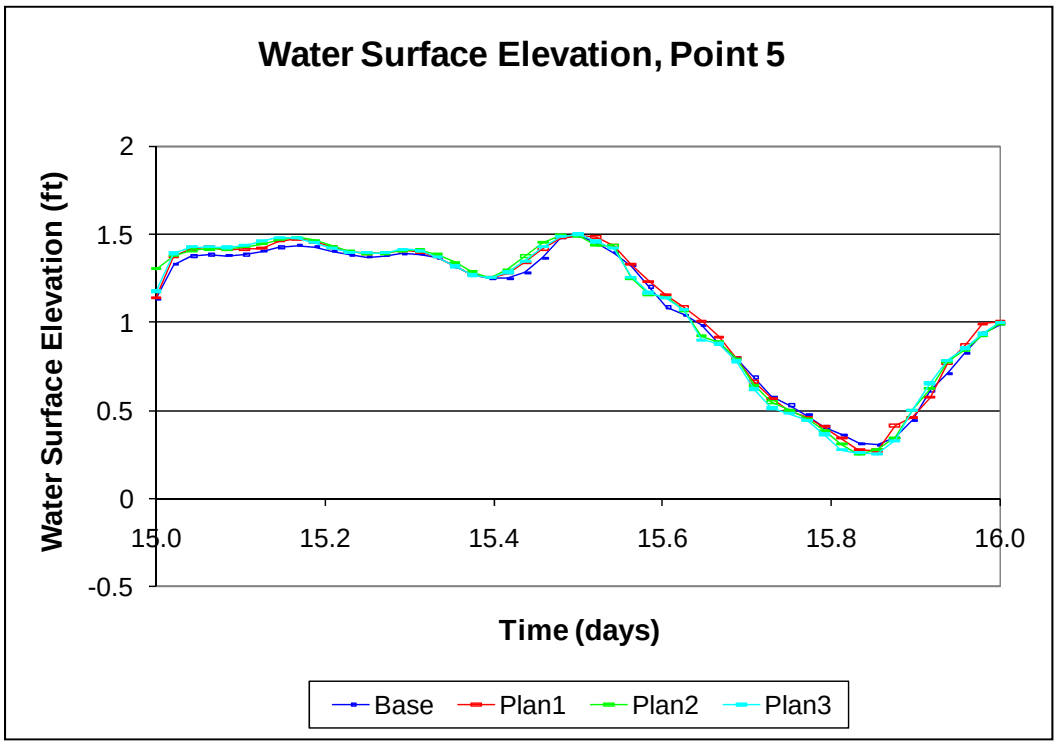

Figure 158. Water surface comparison for day 15 at point 5 for Initial plan set.

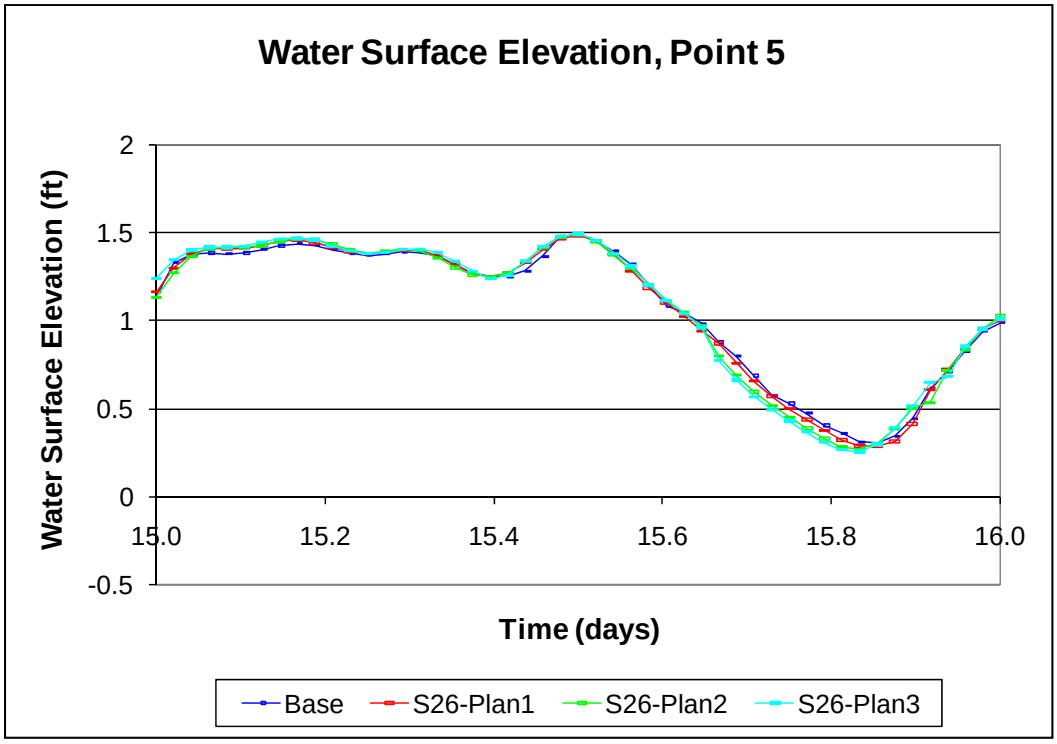

Figure 159. Water surface comparison for day 15 at point 5 for Station 26 plan set.

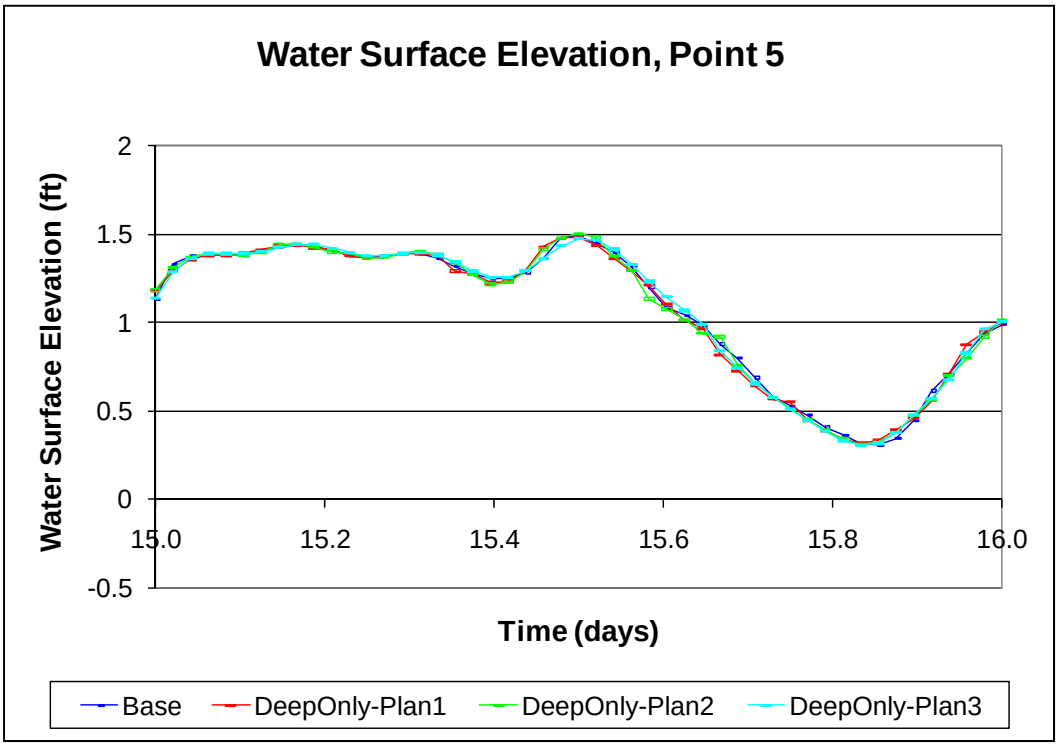

Figure 160. Water surface comparison for day 15 at point 5 for Deepen Only plan set.

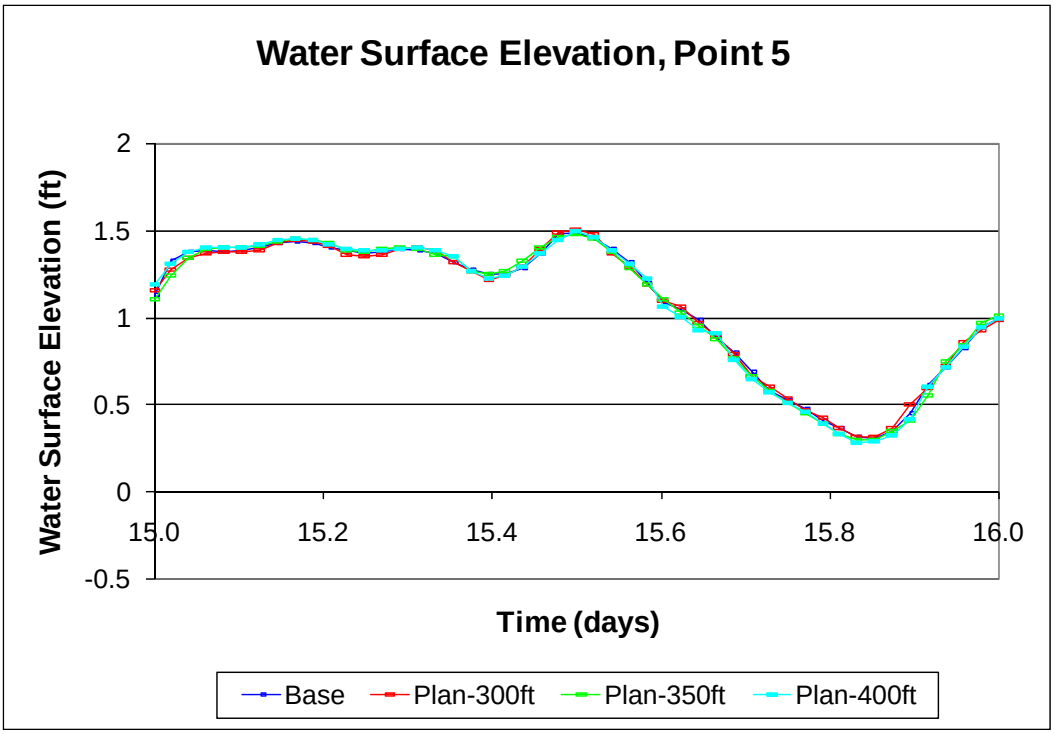

Figure 161. Water surface comparison for day 15 at point 5 for 300/350/400 plan set.

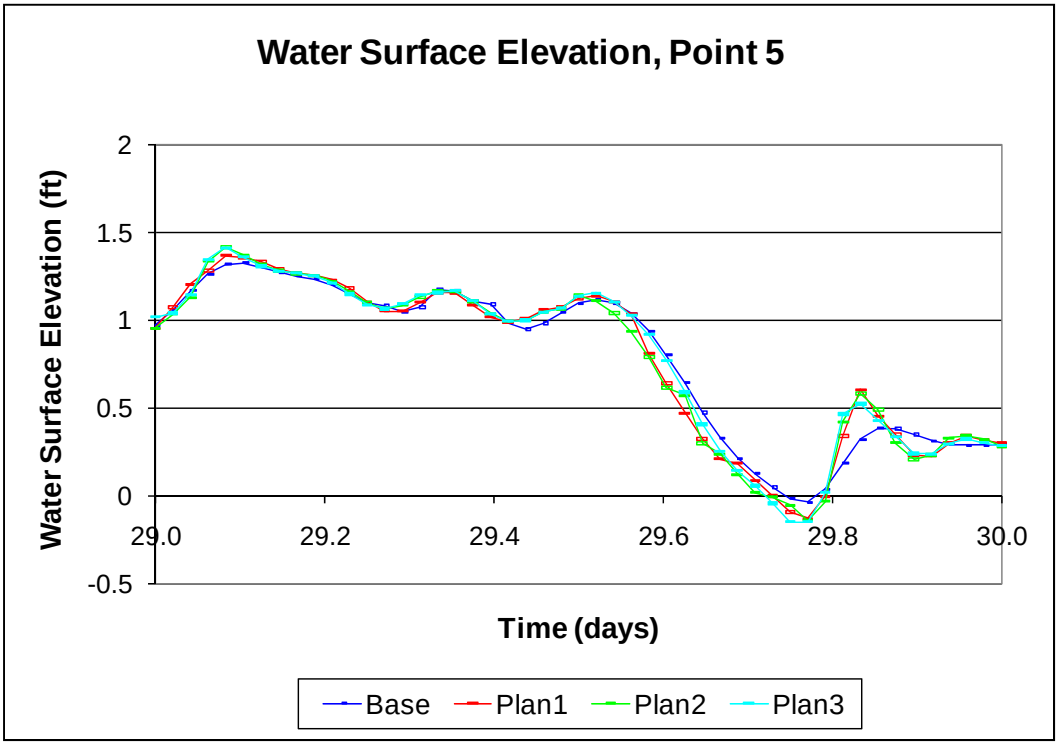

Figure 162. Water surface comparison for day 29 at point 5 for Initial plan set.

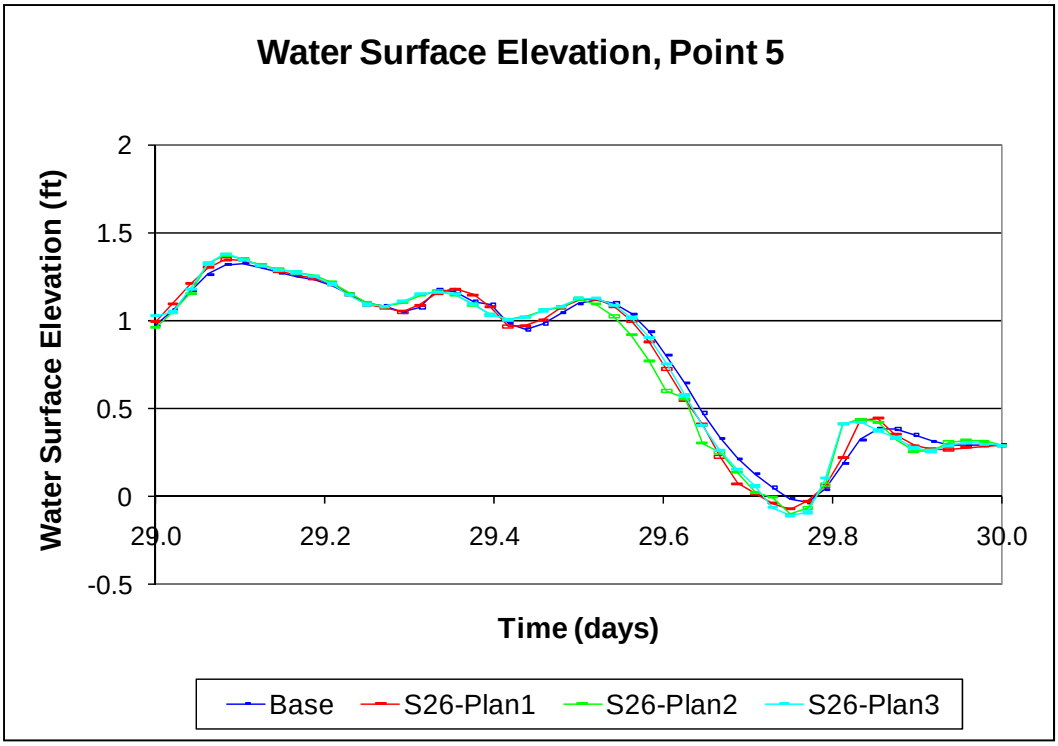

Figure 163. Water surface comparison for day 29 at point 5 for Station 26 plan set.

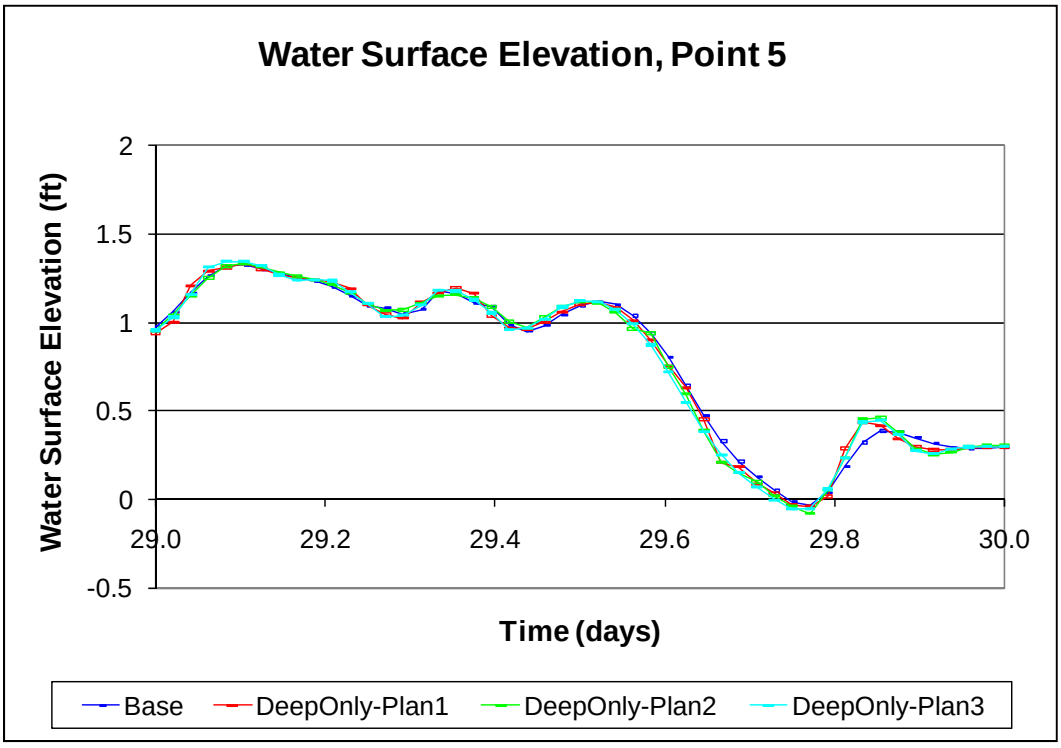

Figure 164. Water surface comparison for day 29 at point 5 for Deepen Only plan set.

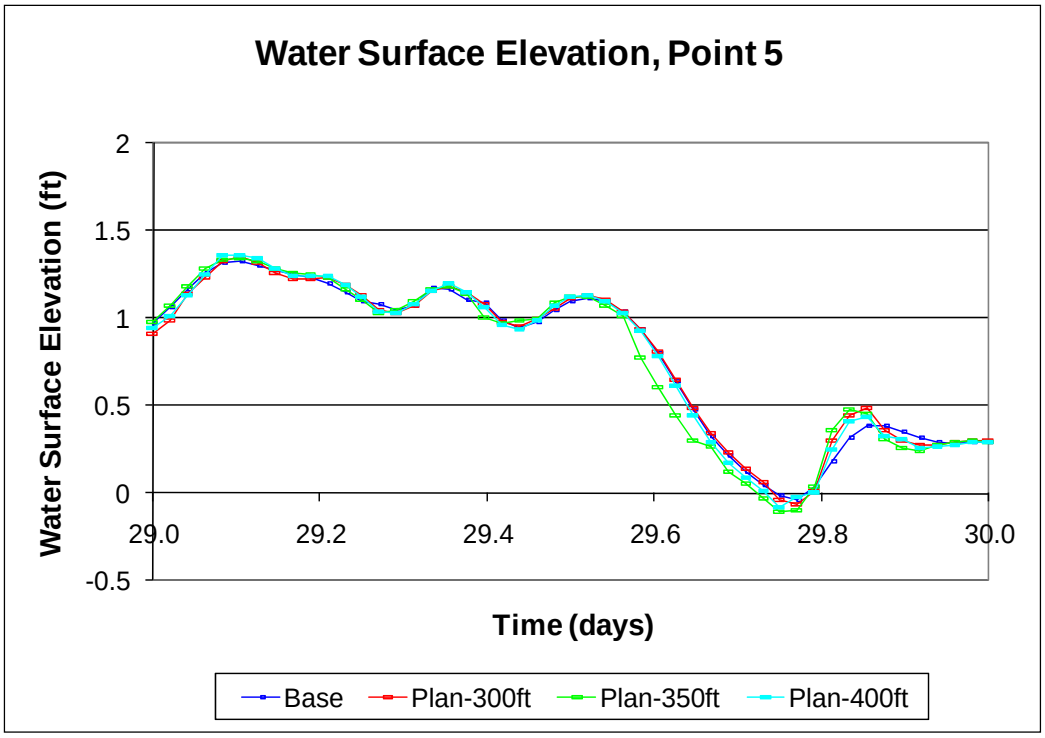

Figure 165. Water surface comparison for day 29 at point 5 for 300/350/400 plan set.

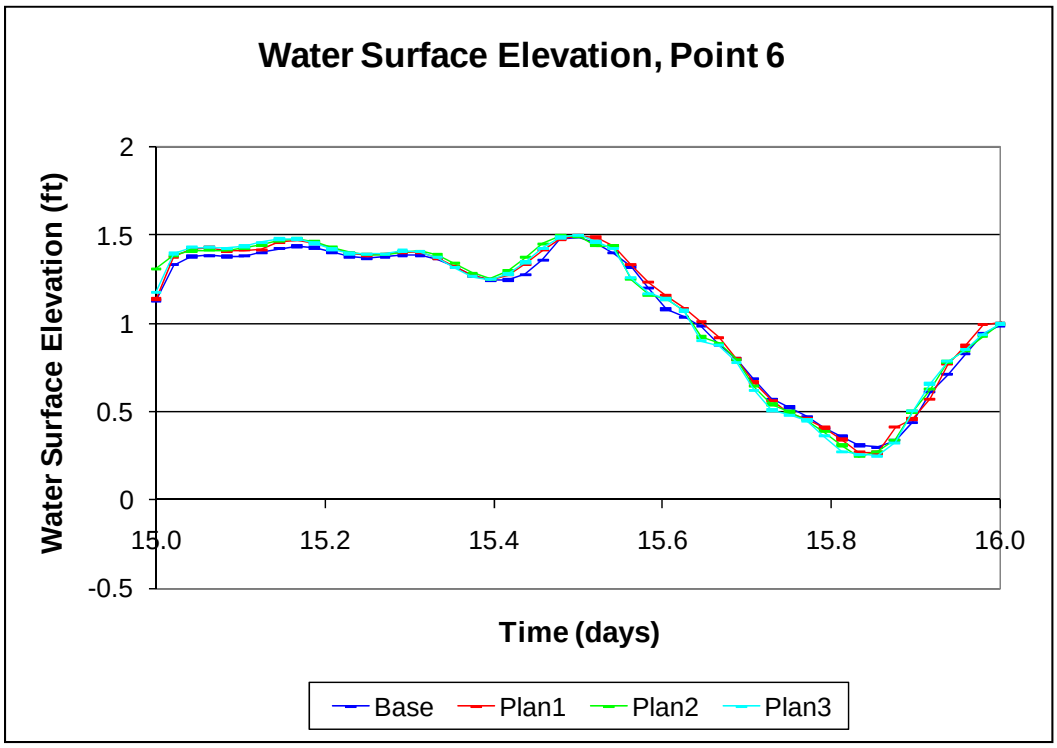

Figure 166. Water surface comparison for day 15 at point 6 for Initial plan set.

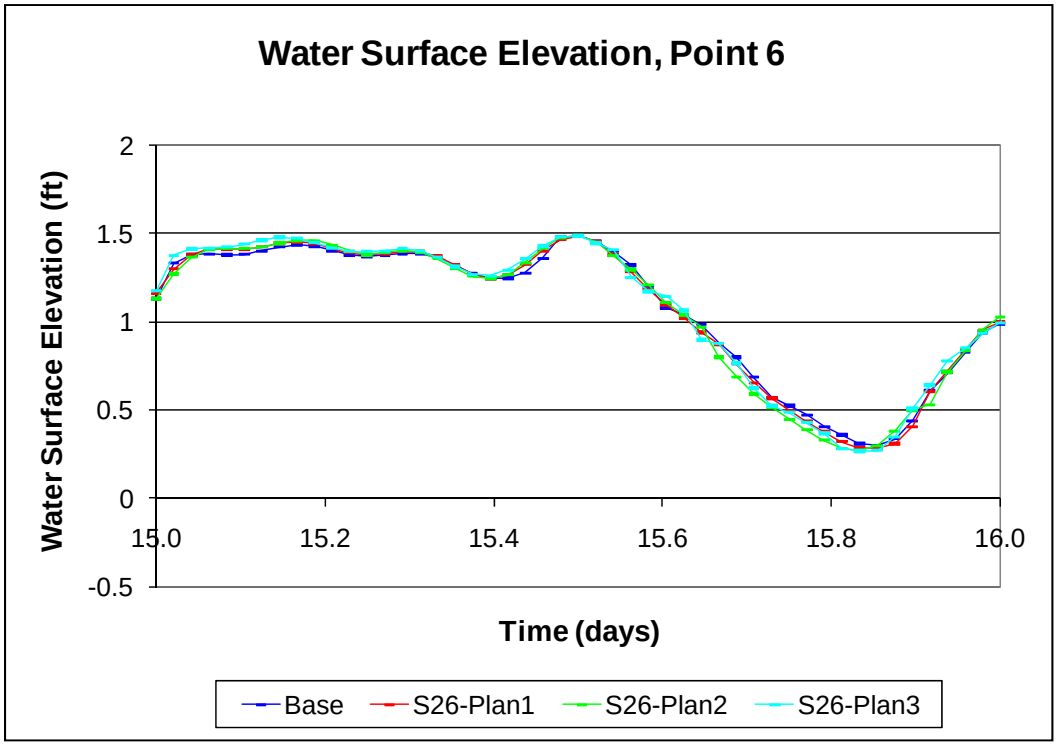

Figure 167. Water surface comparison for day 15 at point 6 for Station 26 plan set.

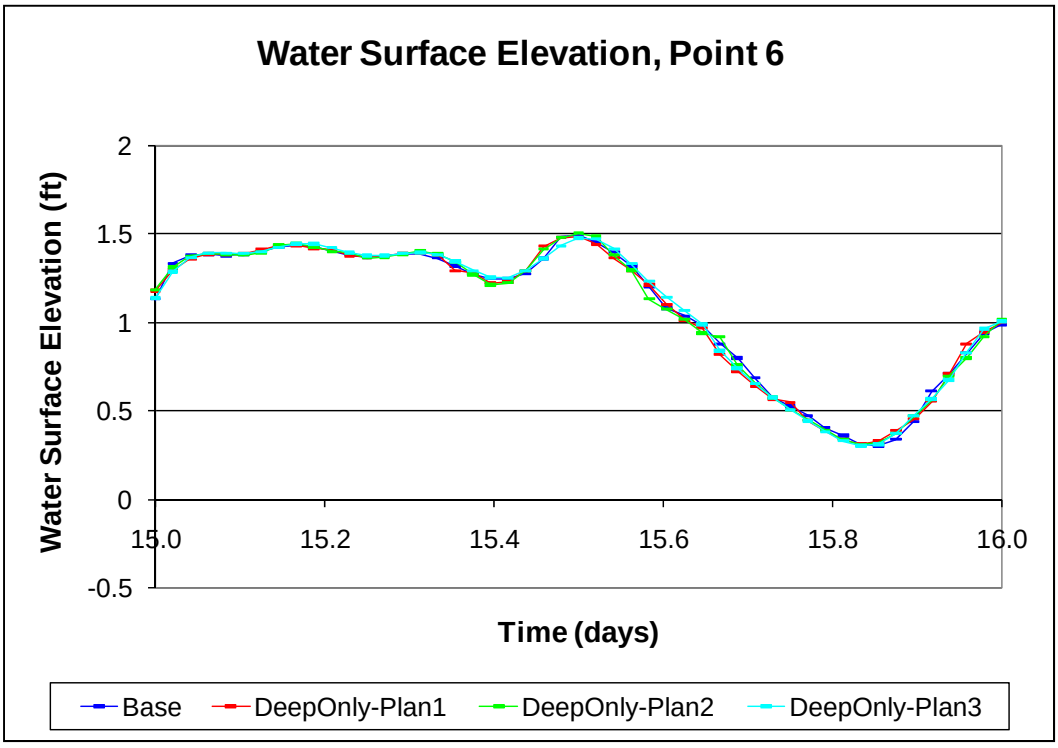

Figure 168. Water surface comparison for day 15 at point 6 for Deepen Only plan set.

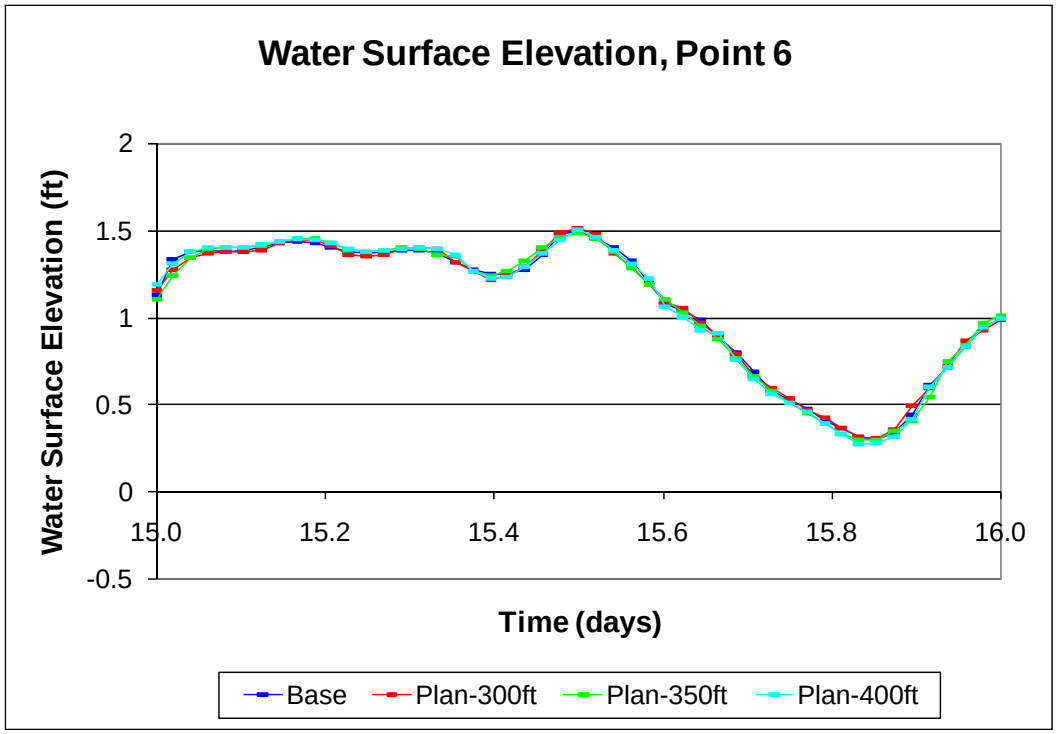

Figure 169. Water surface comparison for day 15 at point 6 for 300/350/400 plan set.

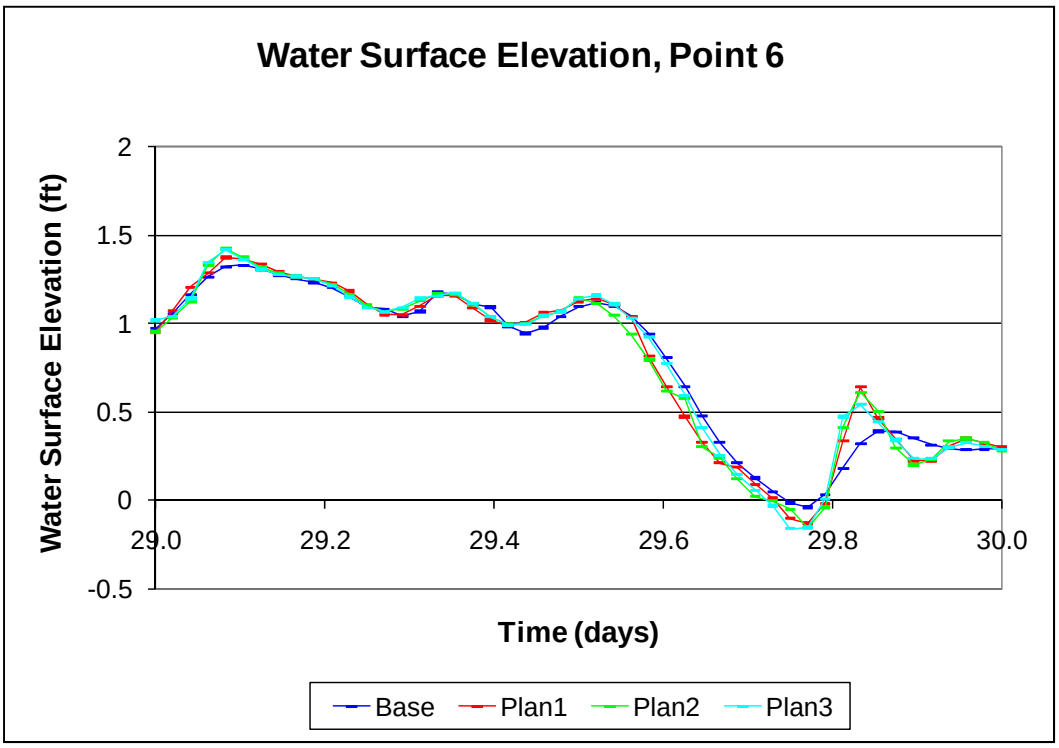

Figure 170. Water surface comparison for day 29 at point 6 for Initial plan set.

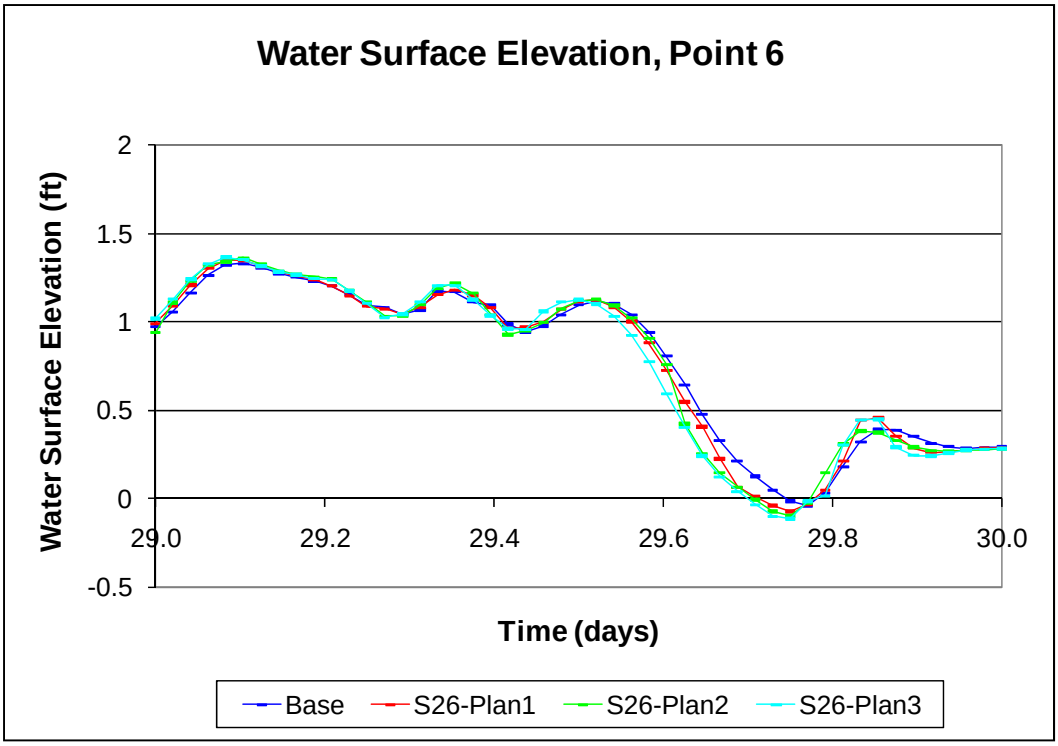

Figure 171. Water surface comparison for day 29 at point 6 for Station 26 plan set.

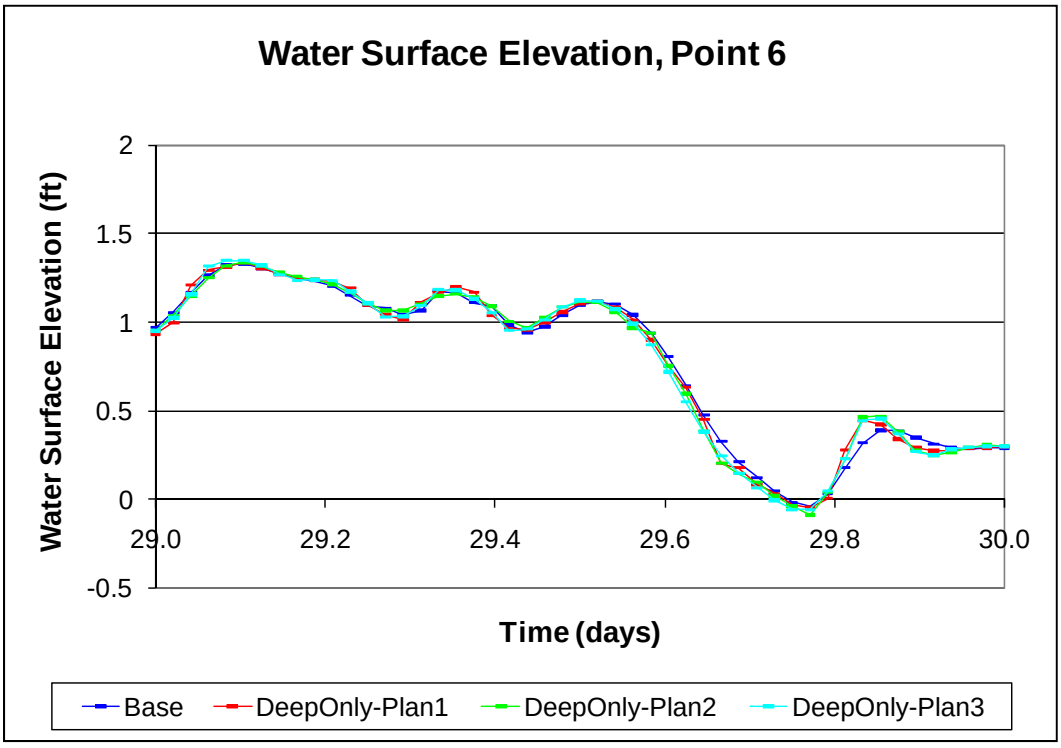

Figure 172. Water surface comparison for day 29 at point 6 for Deepen Only plan set.

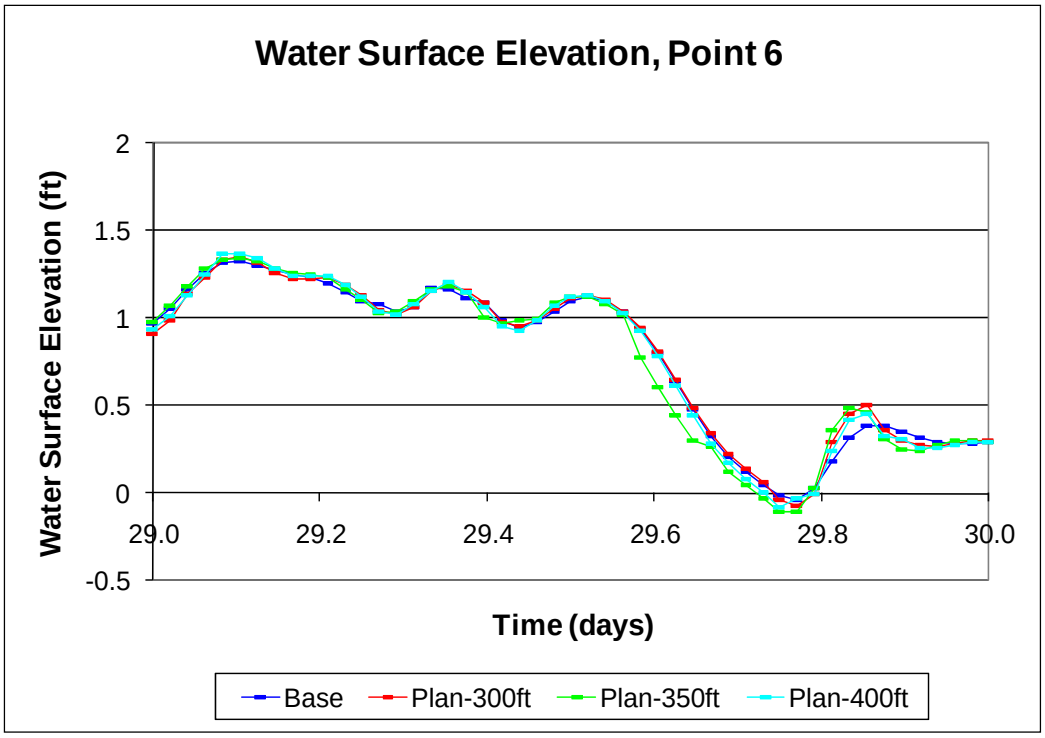

Figure 173. Water surface comparison for day 29 at point 6 for 300/350/400 plan set.

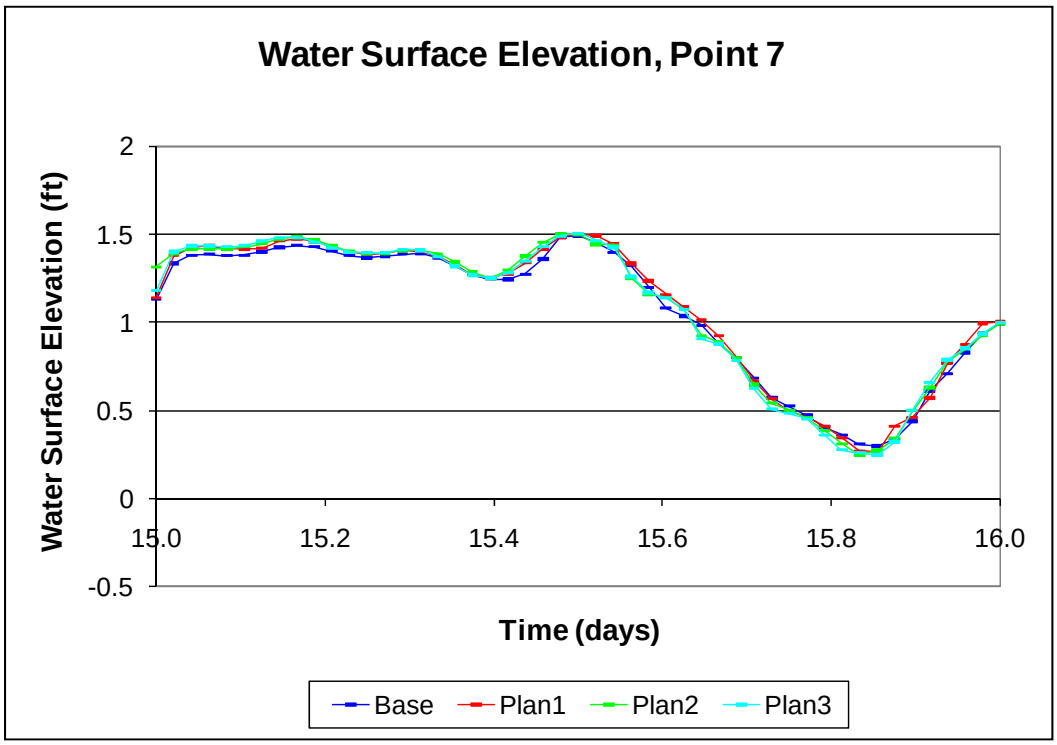

Figure 174. Water surface comparison for day 15 at point 7 for Initial plan set.

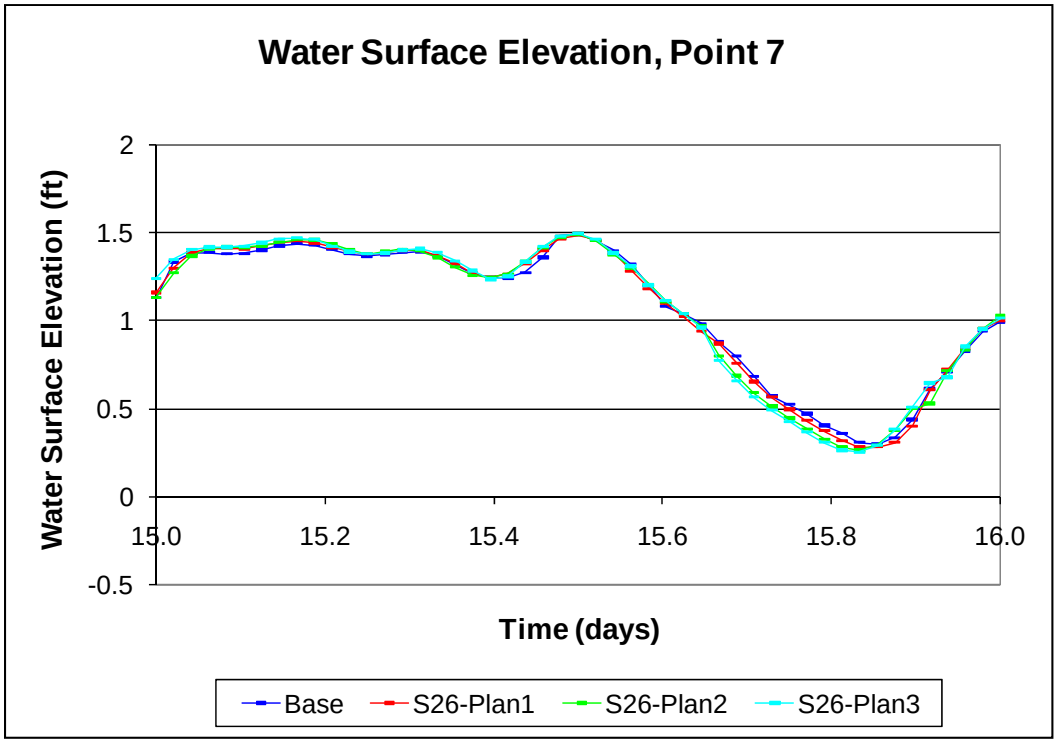

Figure 175. Water surface comparison for day 15 at point 7 for Station 26 plan set.

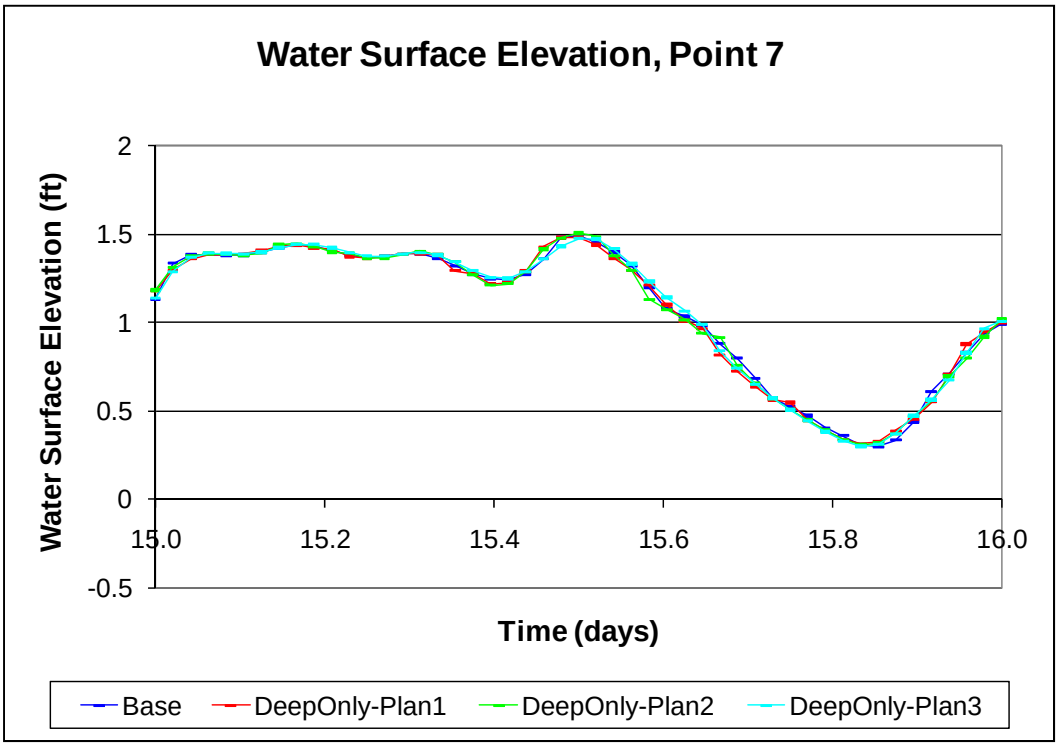

Figure 176. Water surface comparison for day 15 at point 7 for Deepen Only plan set.

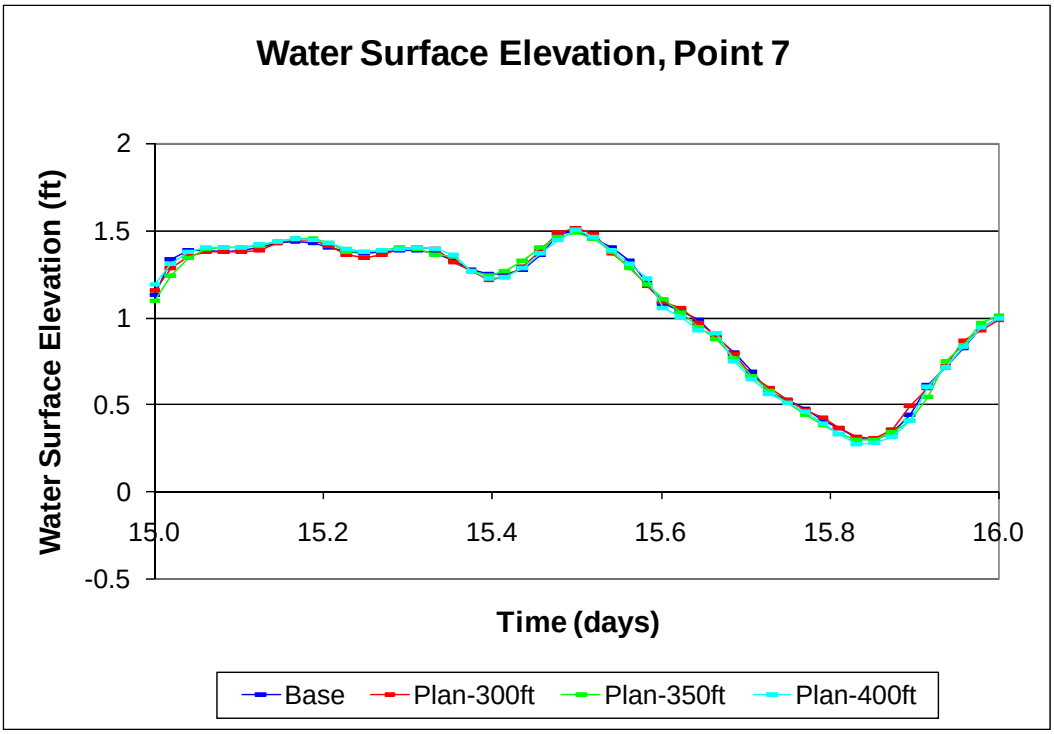

Figure 177. Water surface comparison for day 15 at point 7 for 300/350/400 plan set.

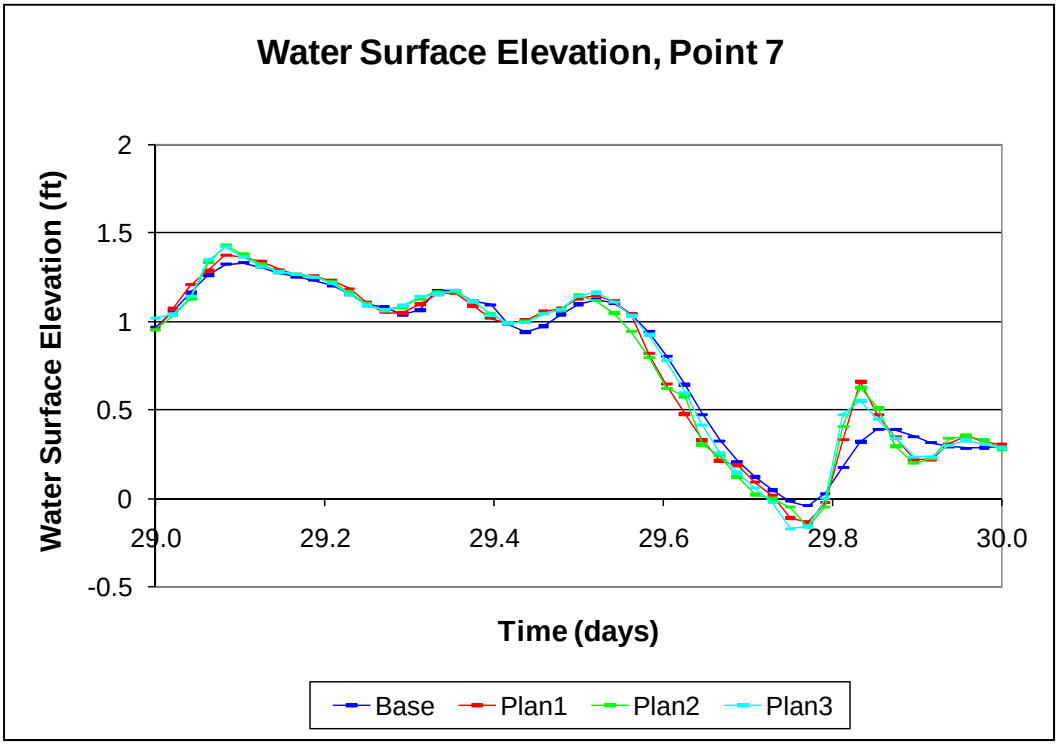

Figure 178. Water surface comparison for day 29 at point 7 for Initial plan set.

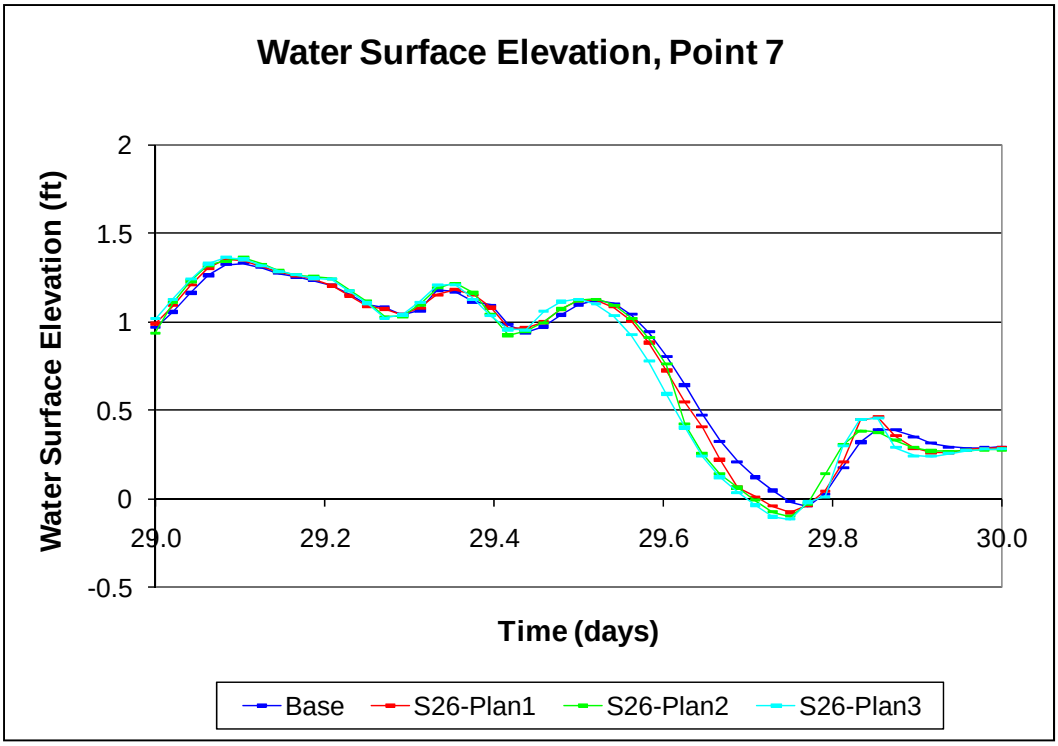

Figure 179. Water surface comparison for day 29 at point 7 for Station 26 plan set.

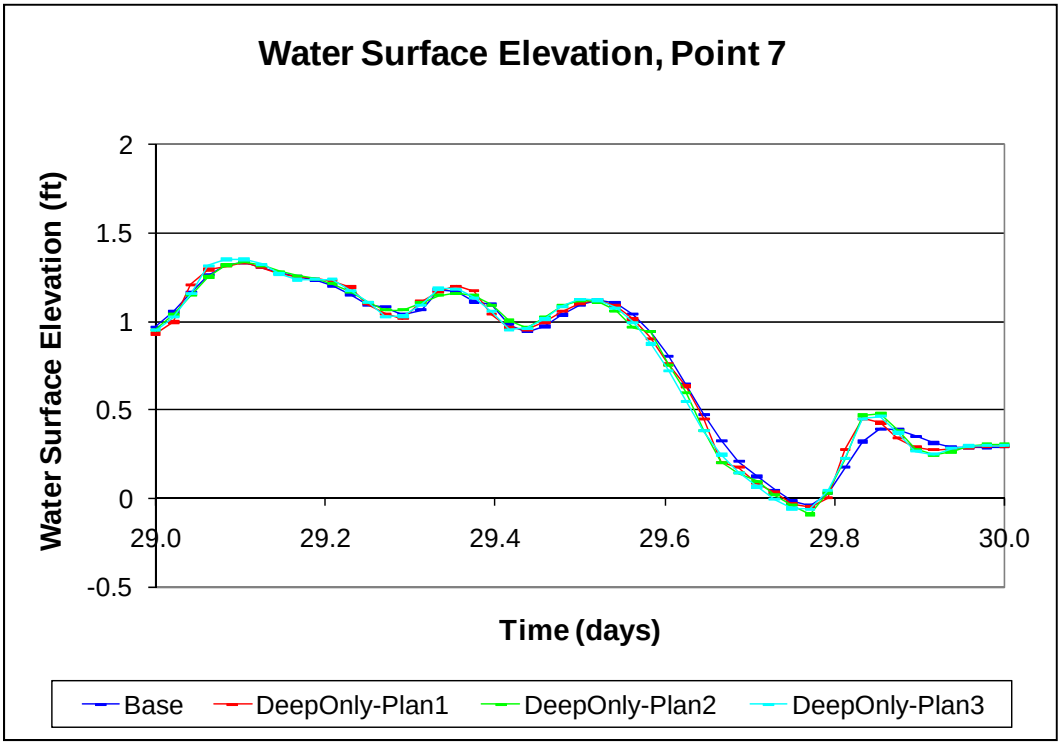

Figure 180. Water surface comparison for day 29 at point 7 for Deepen Only plan set.

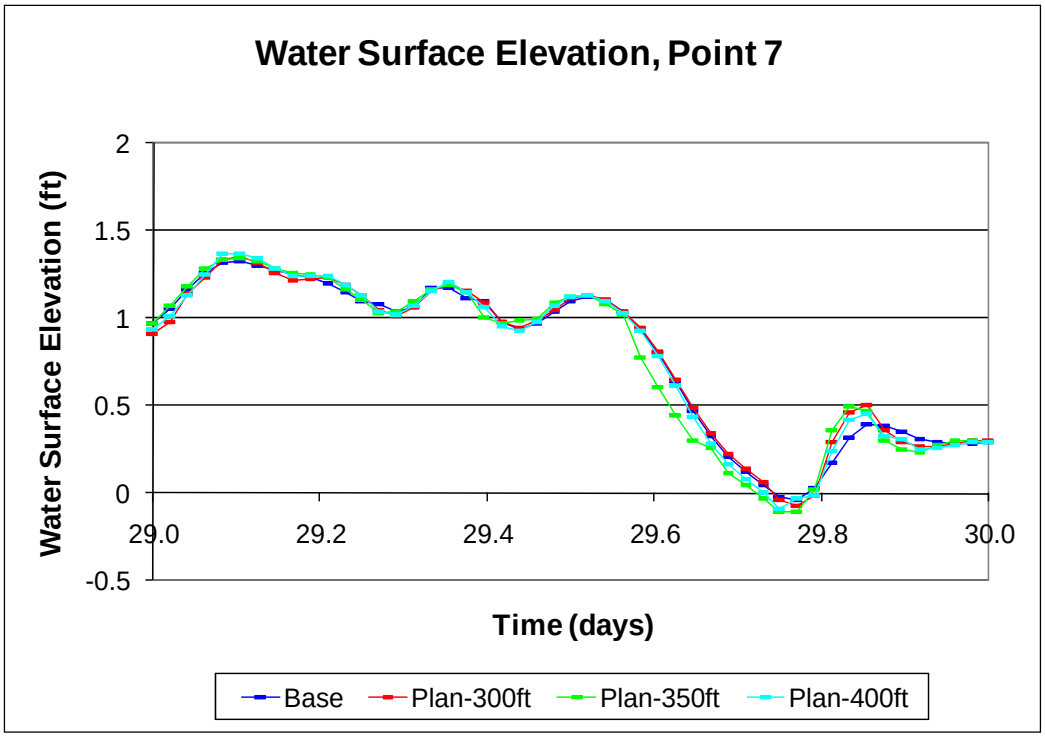

Figure 181. Water surface comparison for day 29 at point 7 for 300/350/400 plan set.

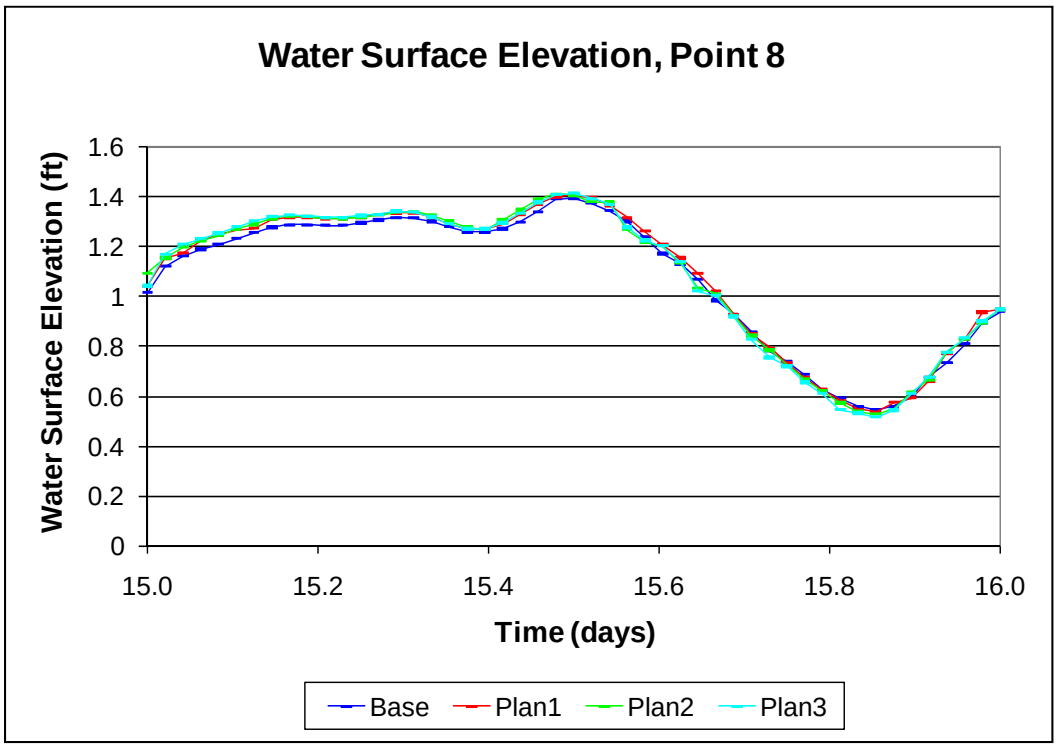

Figure 182. Water surface comparison for day 15 at point 8 for Initial plan set.

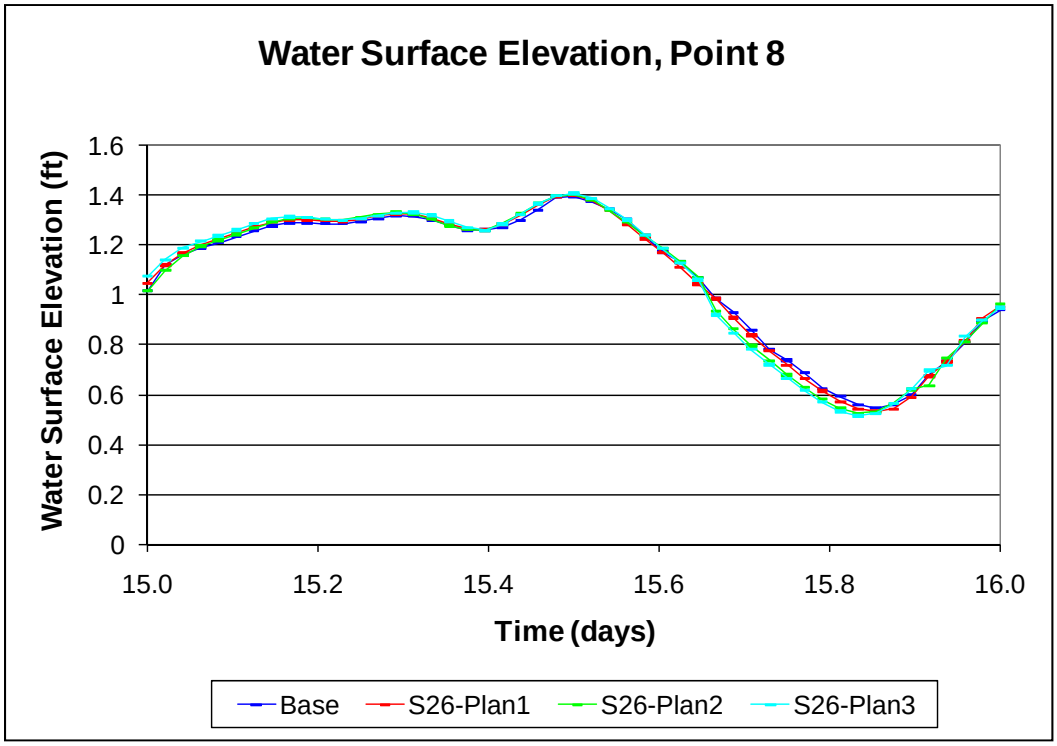

Figure 183. Water surface comparison for day 15 at point 8 for Station 26 plan set.

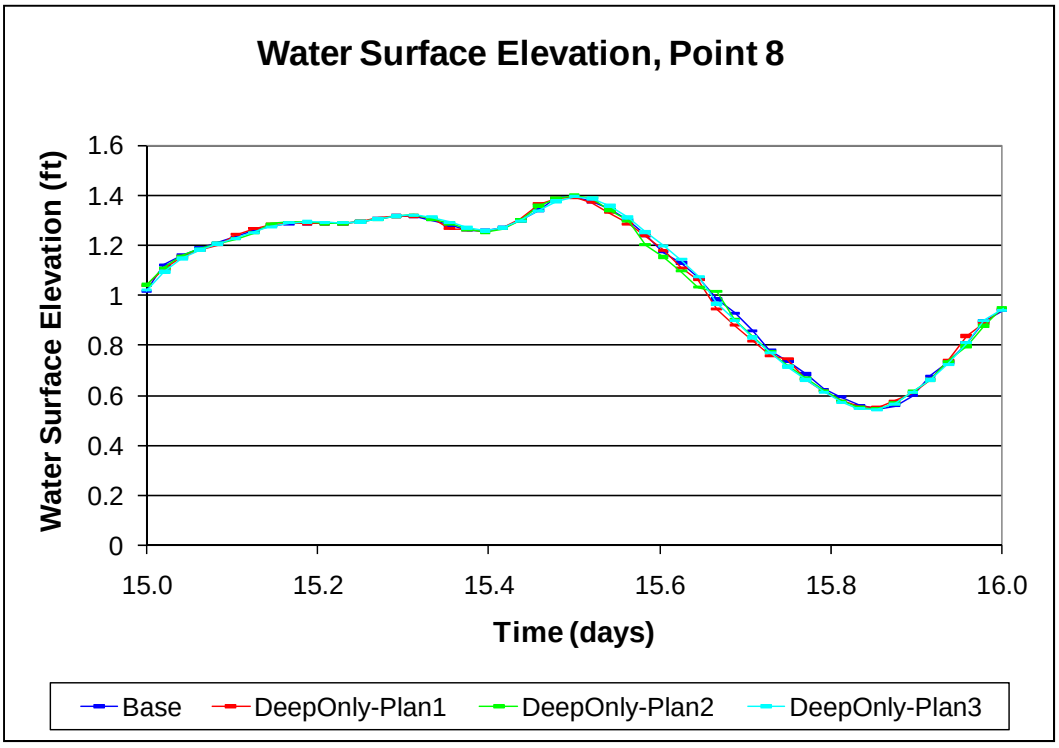

Figure 184. Water surface comparison for day 15 at point 8 for Deepen Only plan set.

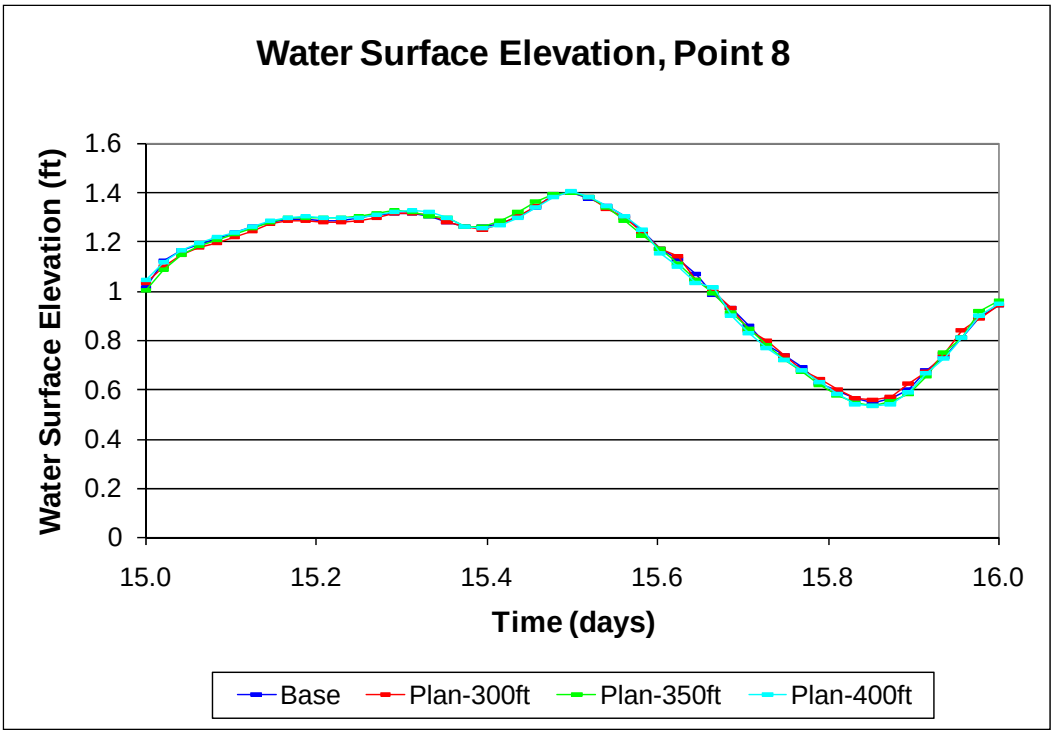

Figure 185. Water surface comparison for day 15 at point 8 for 300/350/400 plan set.

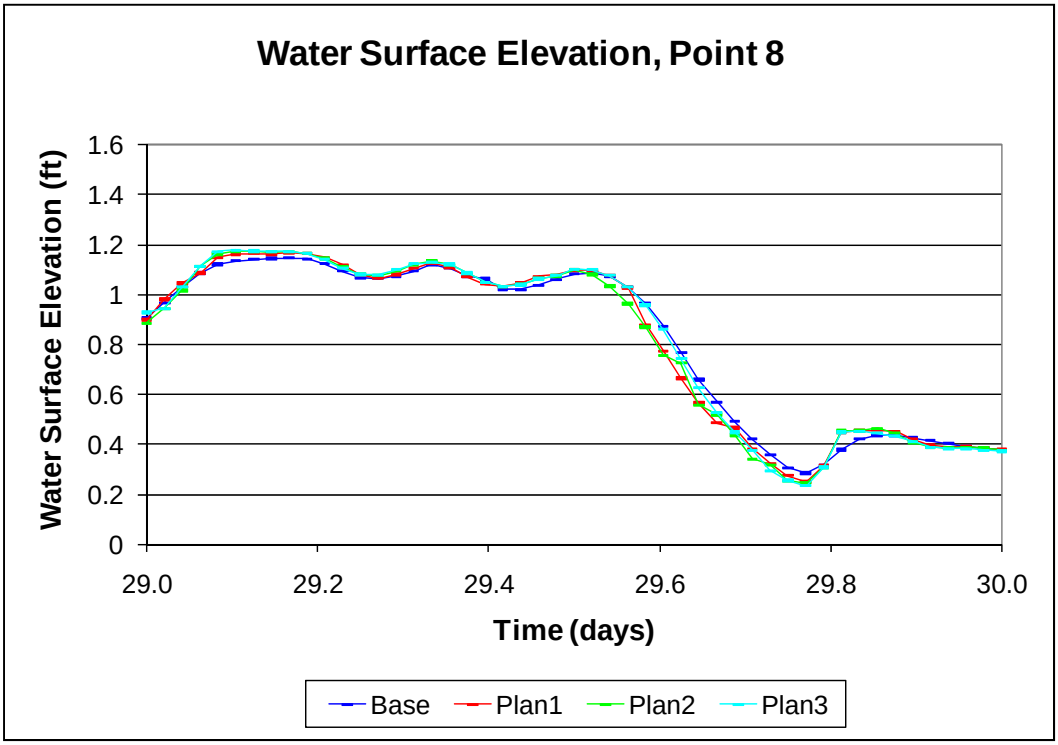

Figure 186. Water surface comparison for day 29 at point 8 for Initial plan set.

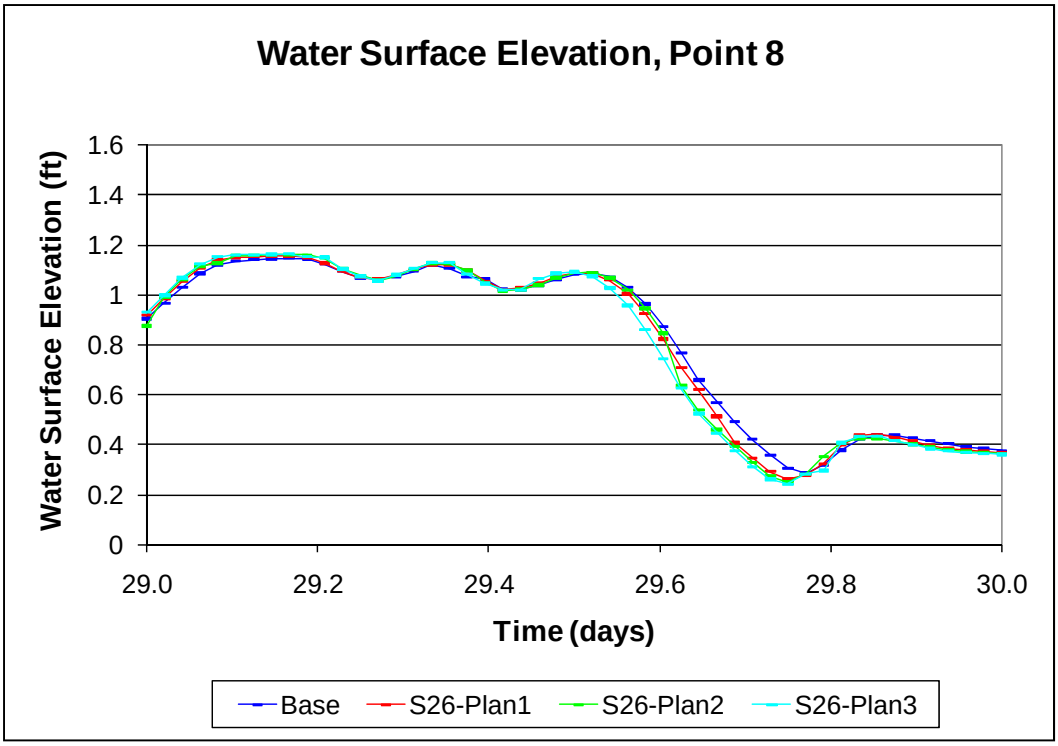

Figure 187. Water surface comparison for day 29 at point 8 for Station 26 plan set.

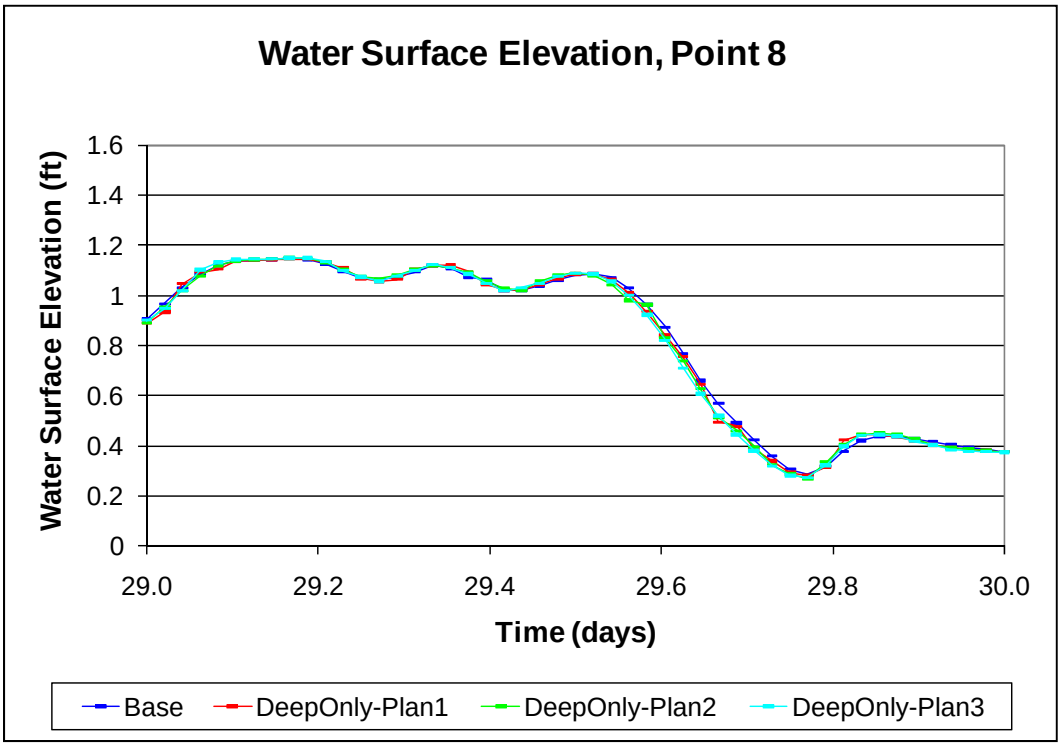

Figure 188. Water surface comparison for day 29 at point 8 for Deepen Only plan set.

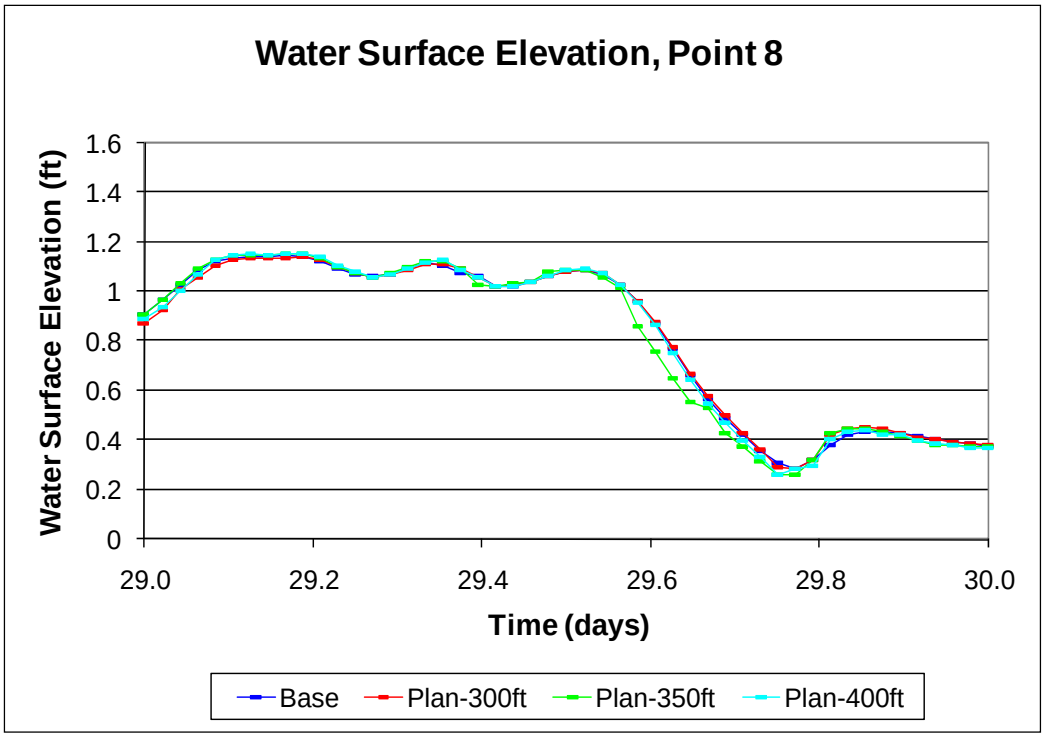

Figure 189. Water surface comparison for day 29 at point 8 for 300/350/400 plan set.

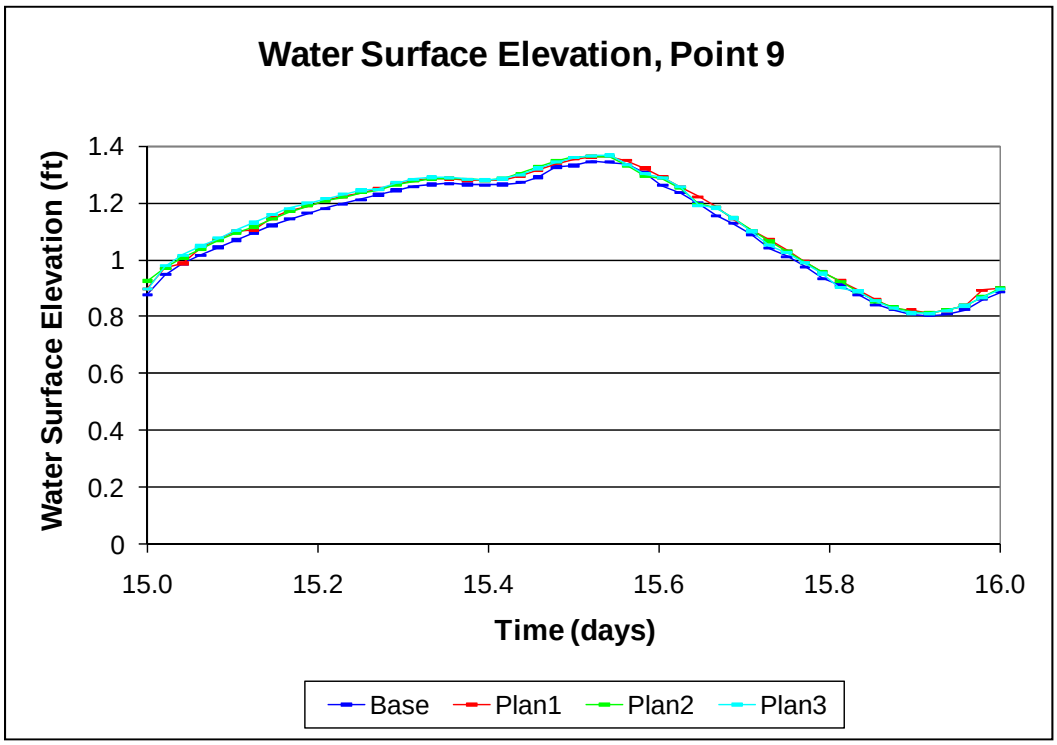

Figure 190. Water surface comparison for day 15 at point 9 for Initial plan set.

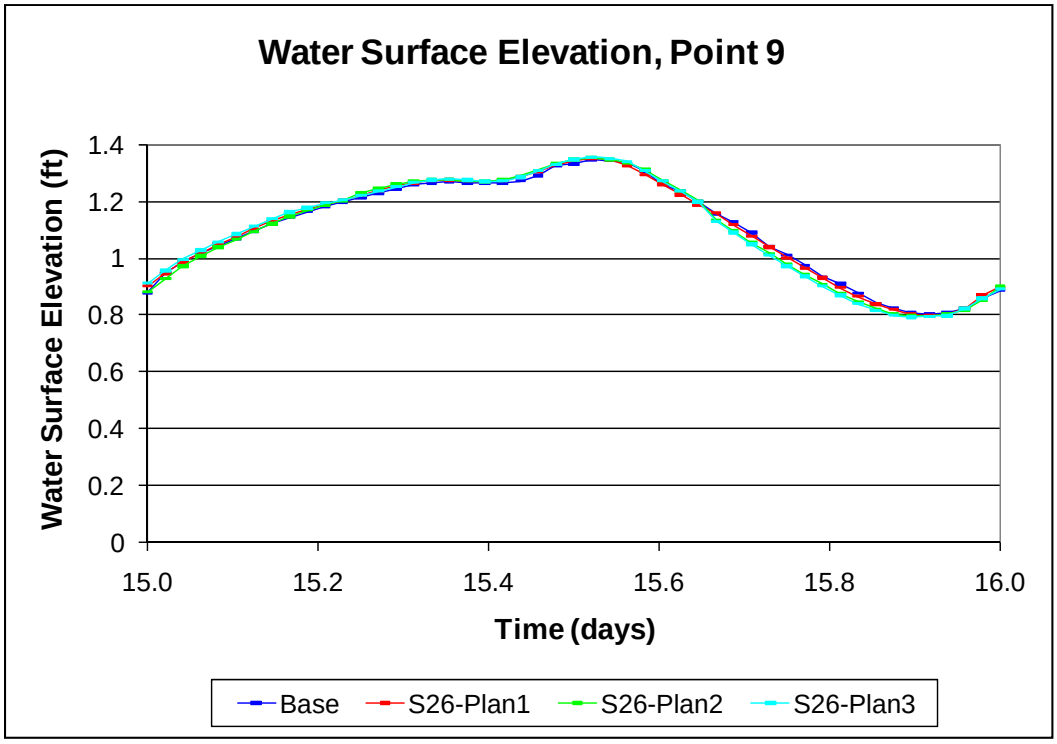

Figure 191. Water surface comparison for day 15 at point 9 for Station 26 plan set.

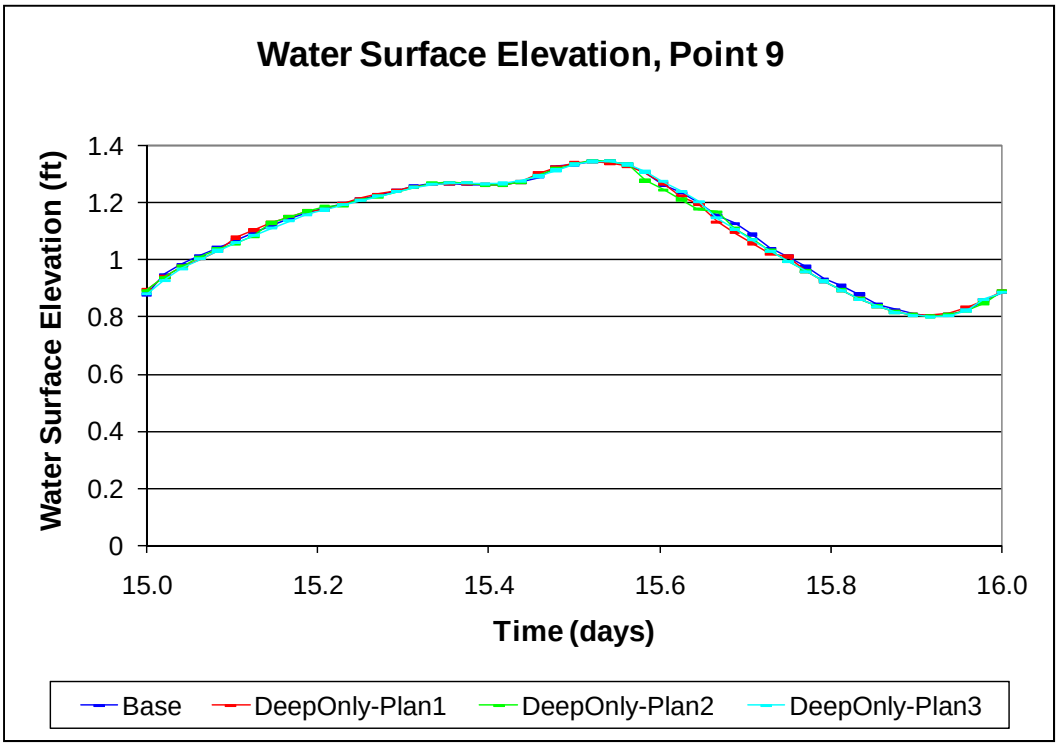

Figure 192. Water surface comparison for day 15 at point 9 for Deepen Only plan set.

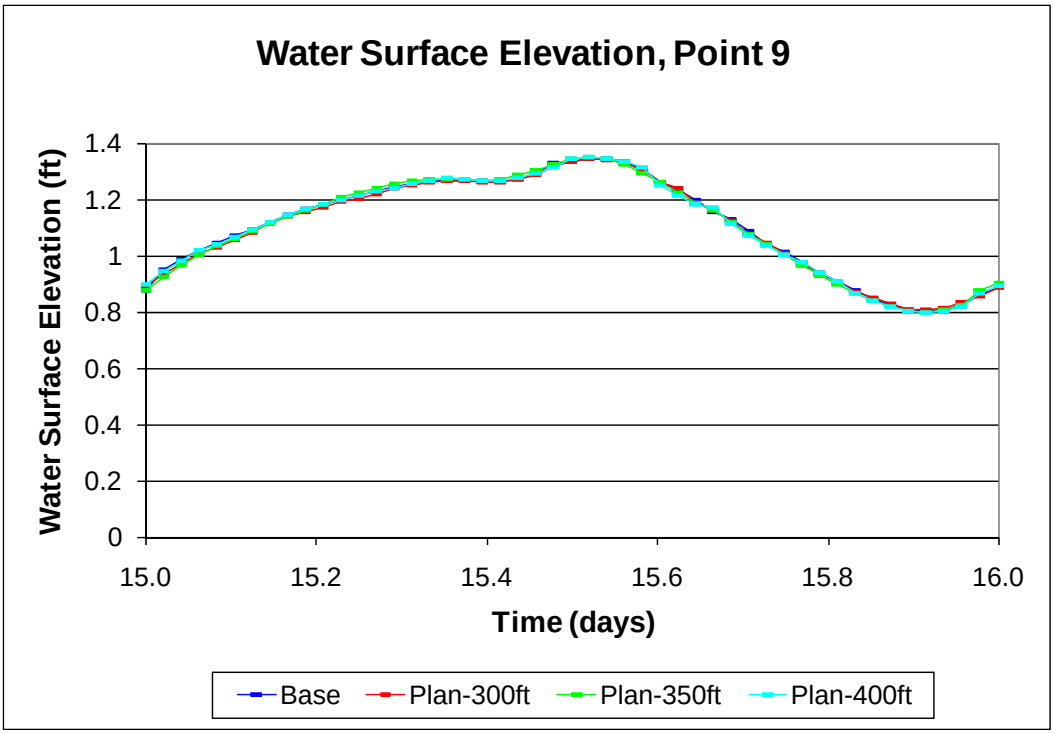

Figure 193. Water surface comparison for day 15 at point 9 for 300/350/400 plan set.

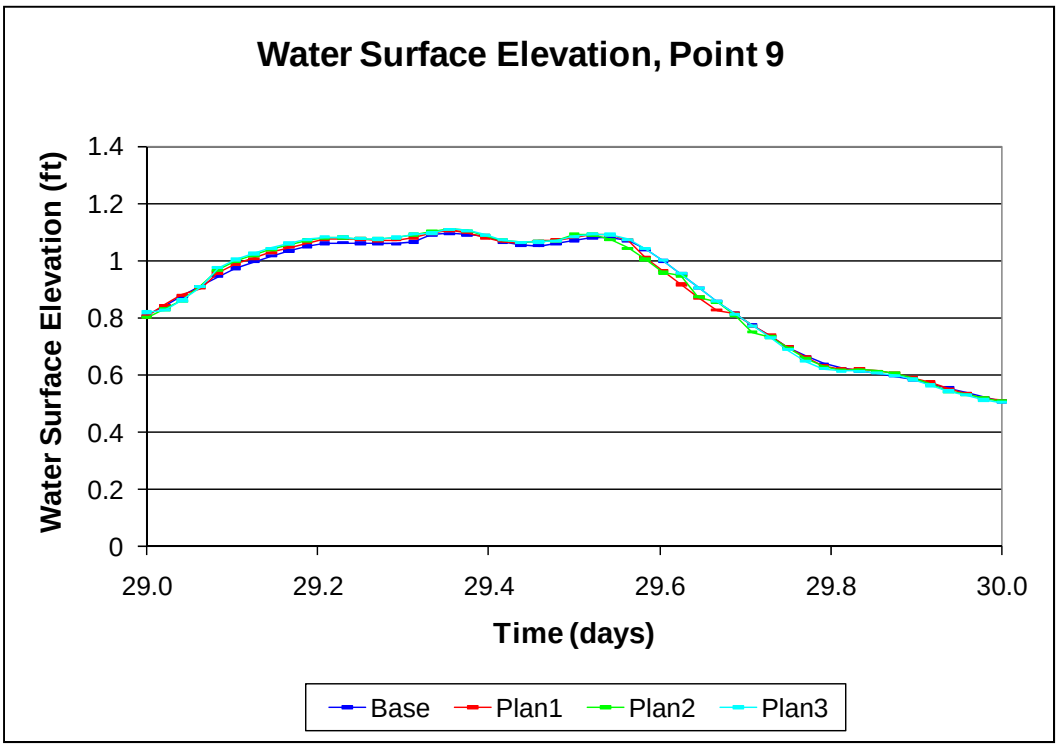

Figure 194. Water surface comparison for day 29 at point 9 for Initial plan set.

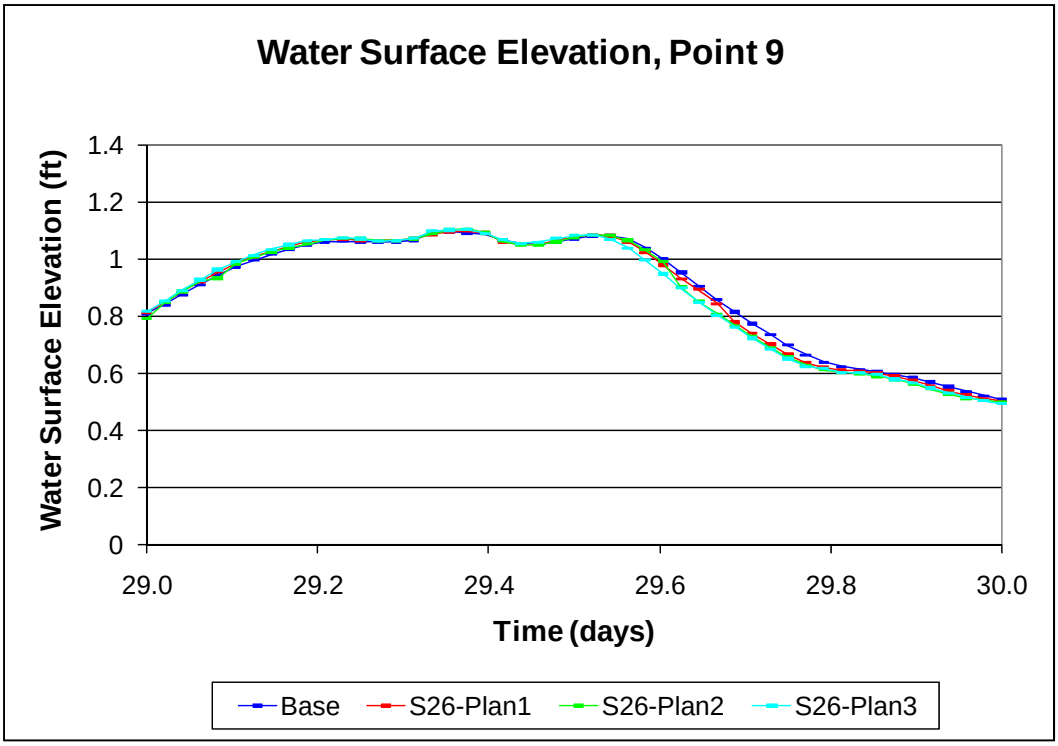

Figure 195. Water surface comparison for day 29 at point 9 for Station 26 plan set.

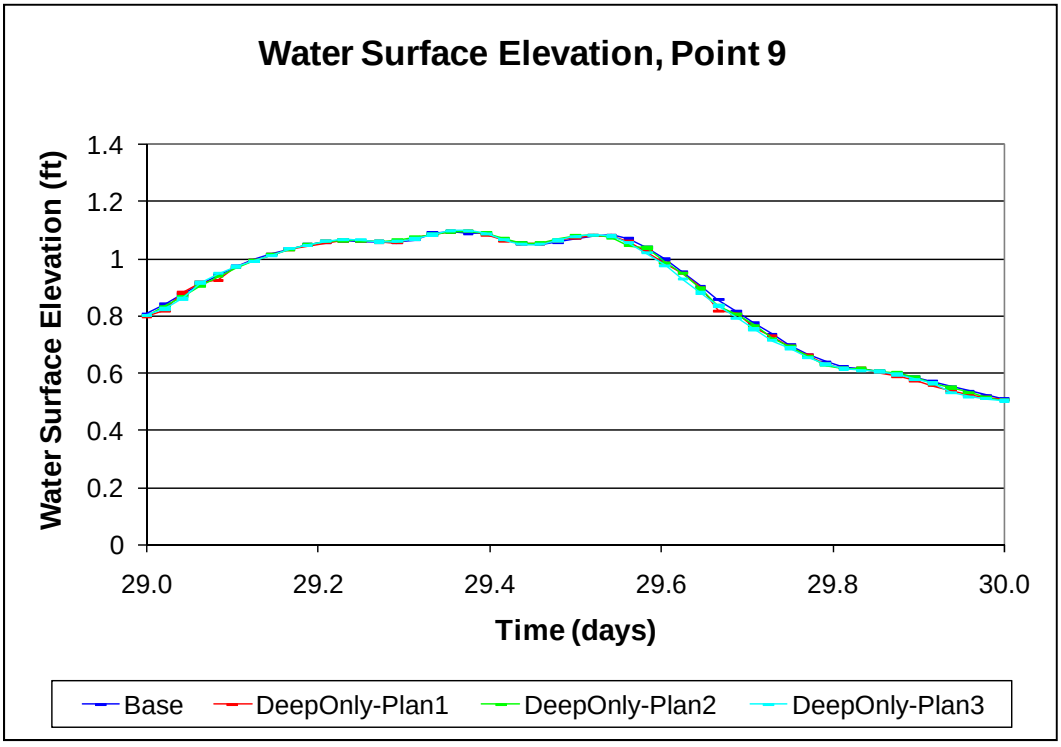

Figure 196. Water surface comparison for day 29 at point 9 for Deepen Only plan set.

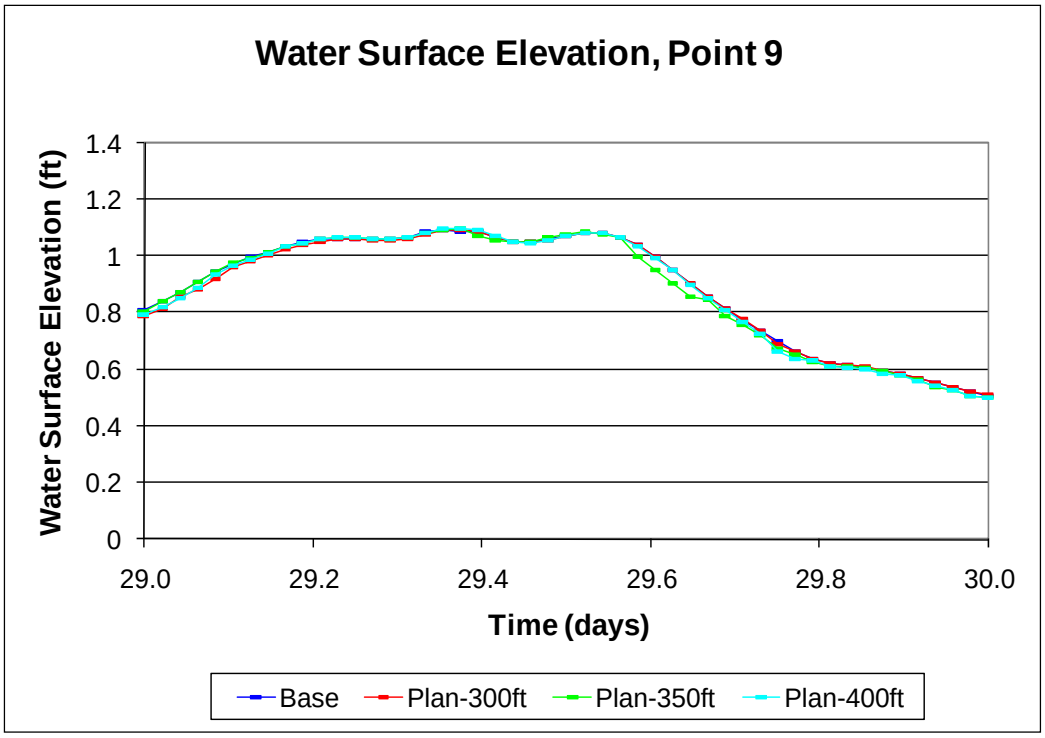

Figure 197. Water surface comparison for day 29 at point 9 for 300/350/400 plan set.

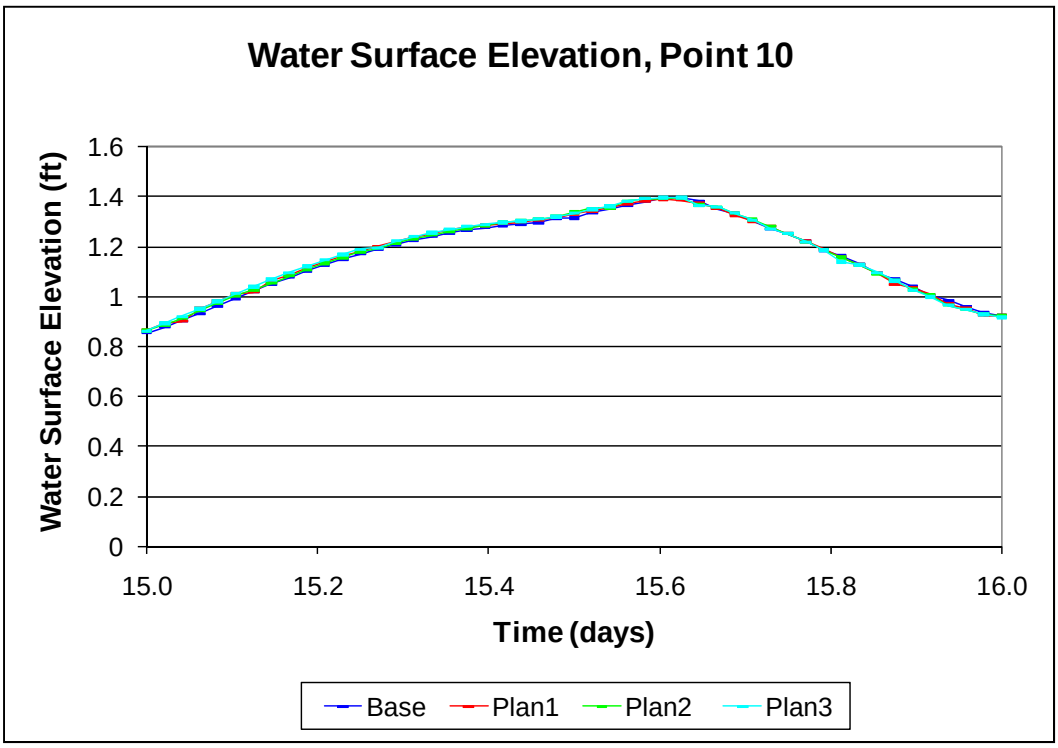

Figure 198. Water surface comparison for day 15 at point 10 for Initial plan set.

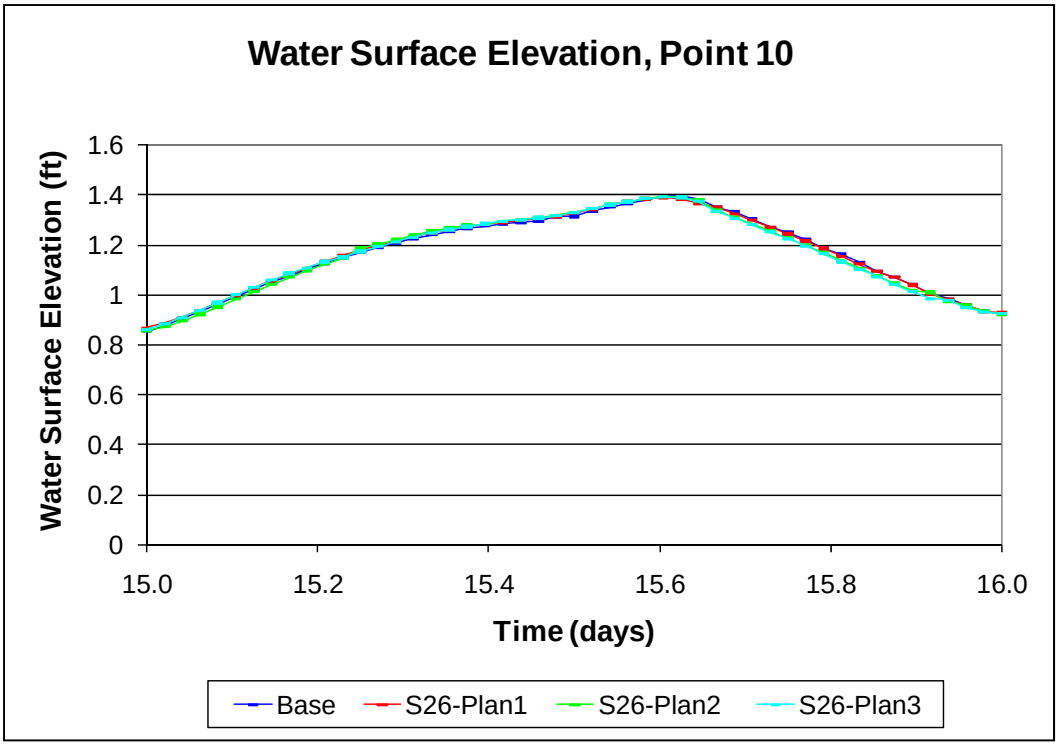

Figure 199. Water surface comparison for day 15 at point 10 for Station 26 plan set.

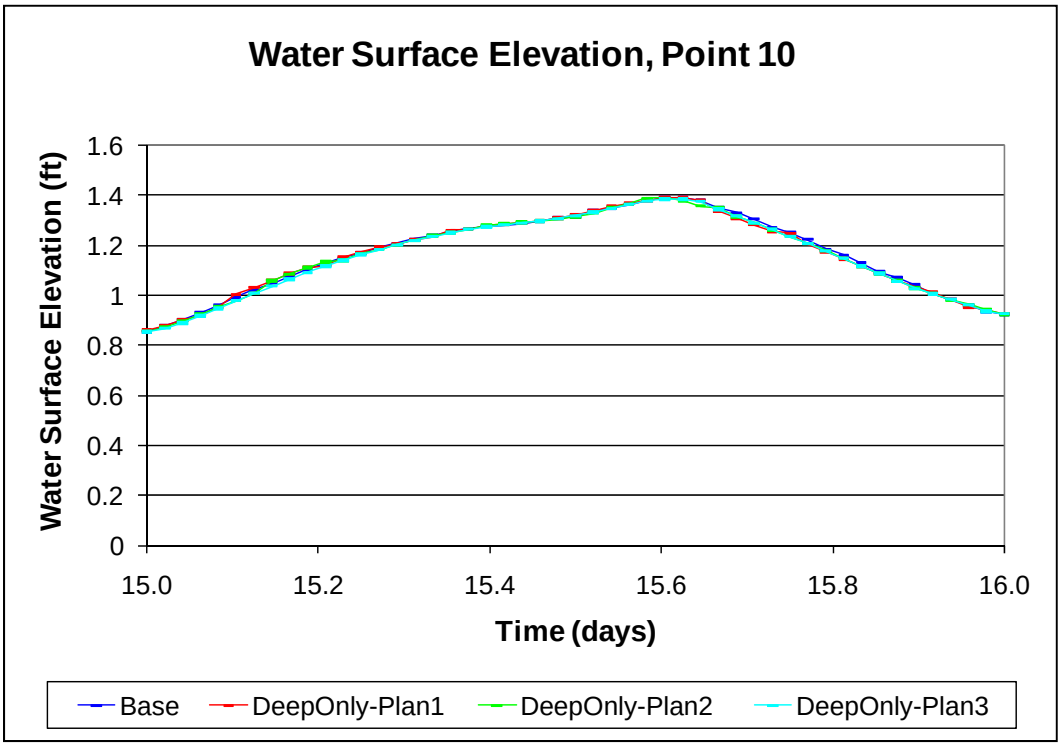

Figure 200. Water surface comparison for day 15 at point 10 for Deepen Only plan set.

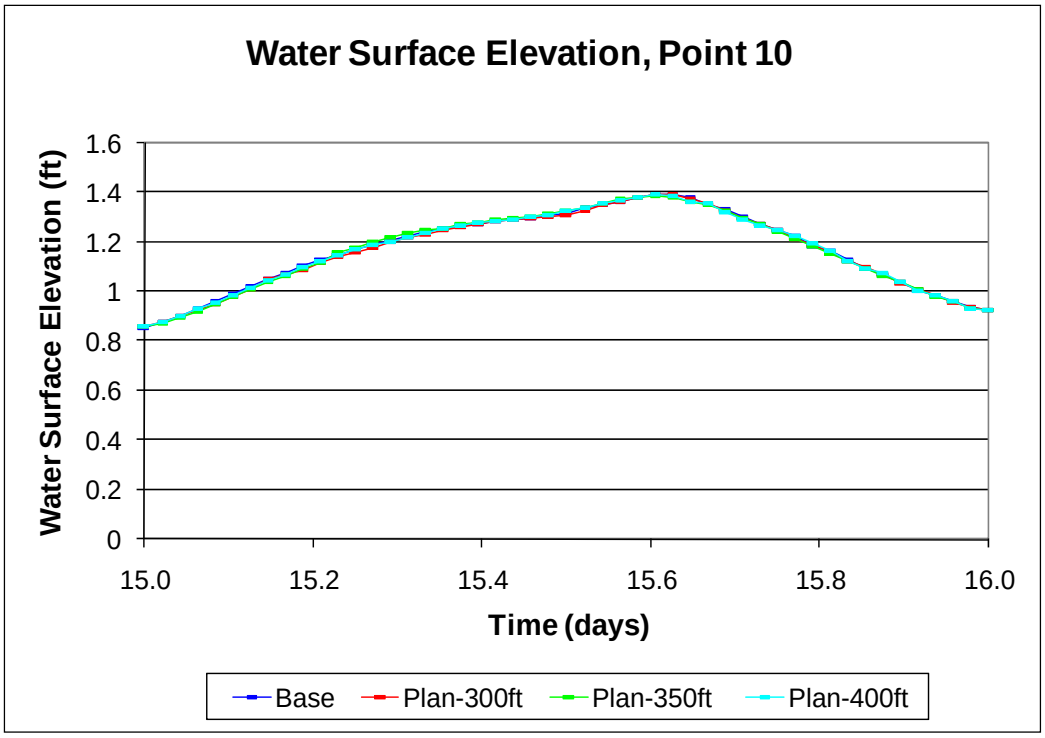

Figure 201. Water surface comparison for day 15 at point 10 for 300/350/400 plan set.

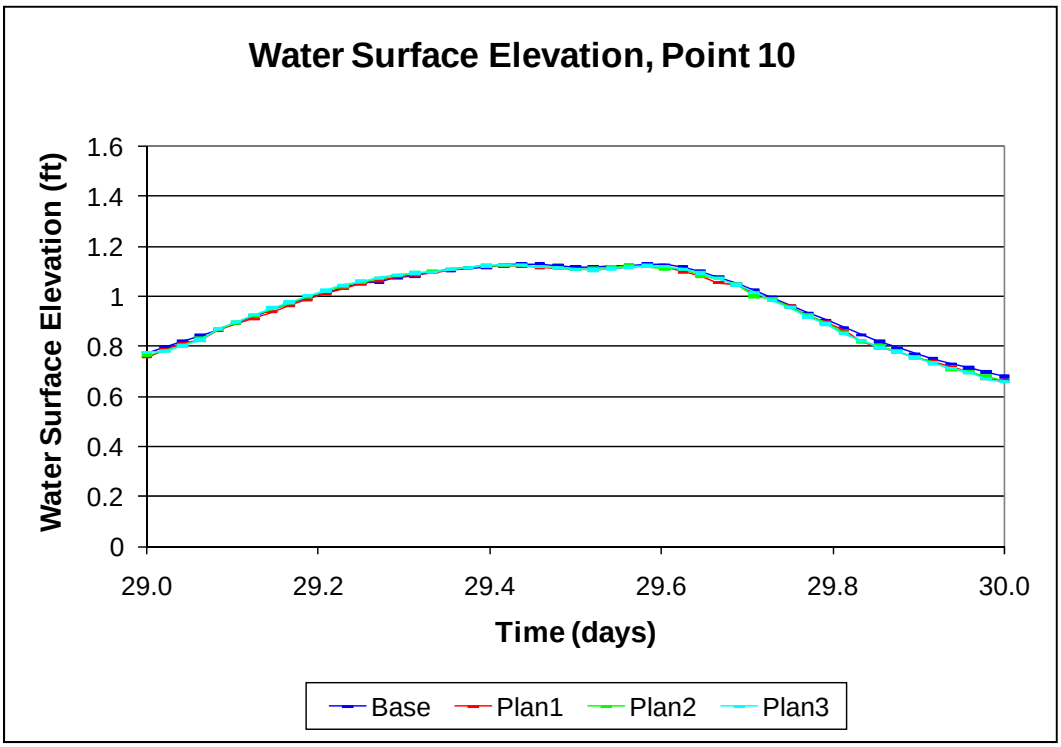

Figure 202. Water surface comparison for day 29 at point 10 for Initial plan set.

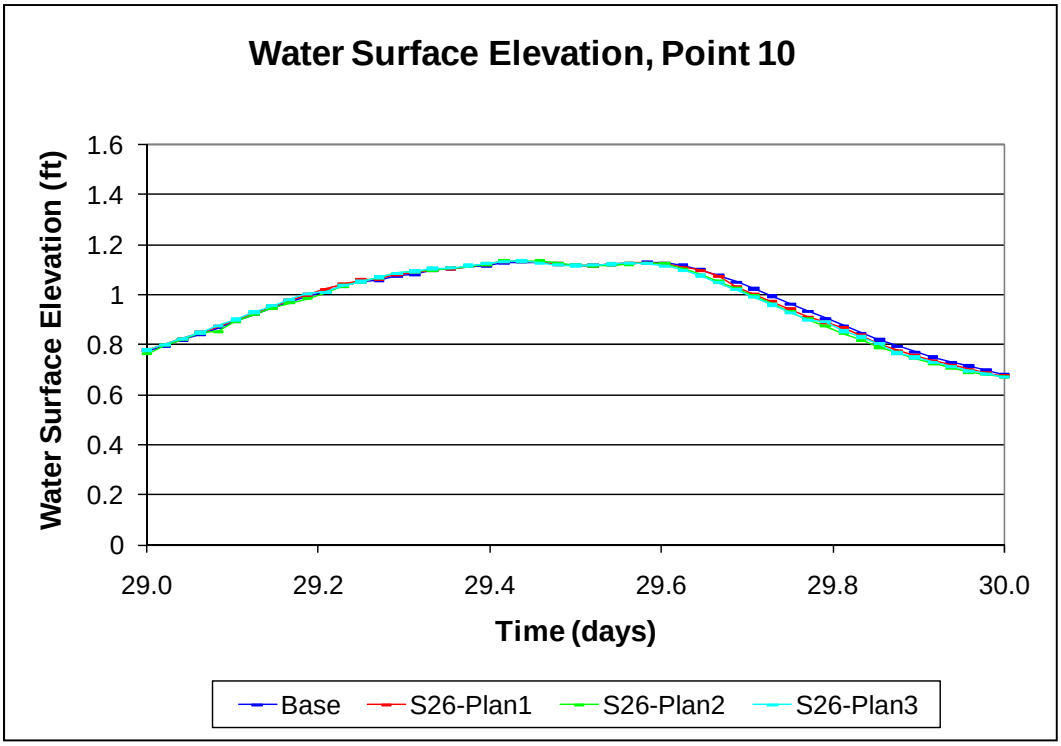

Figure 203. Water surface comparison for day 29 at point 10 for Station 26 plan set.

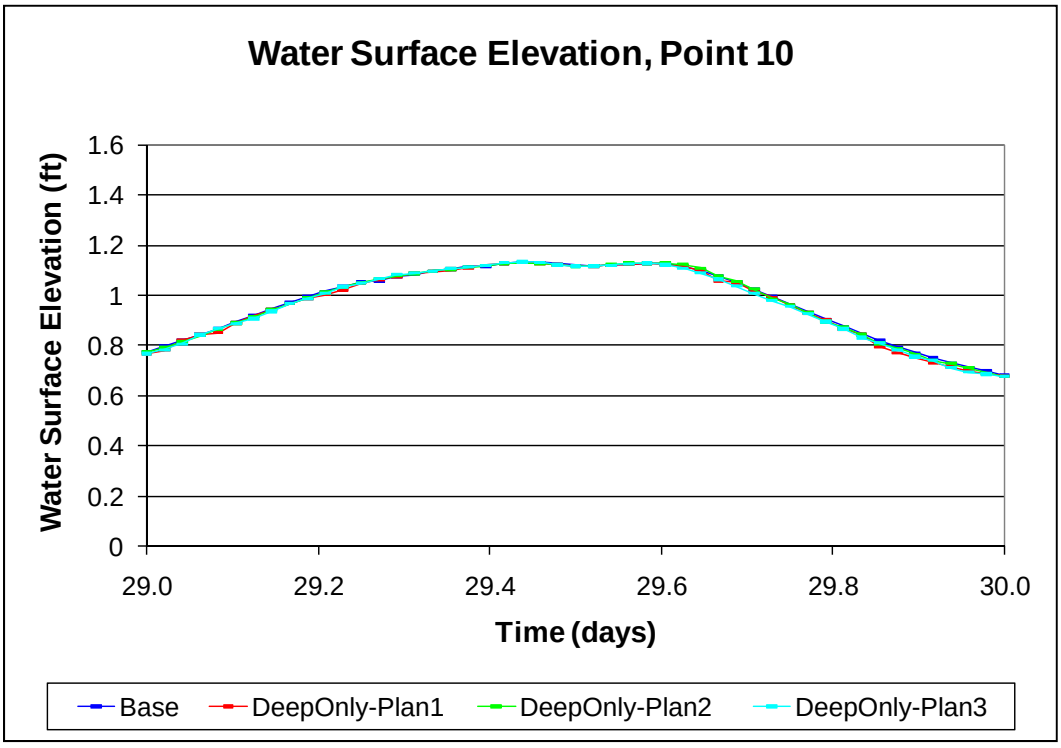

Figure 204. Water surface comparison for day 29 at point 10 for Deepen Only plan set.

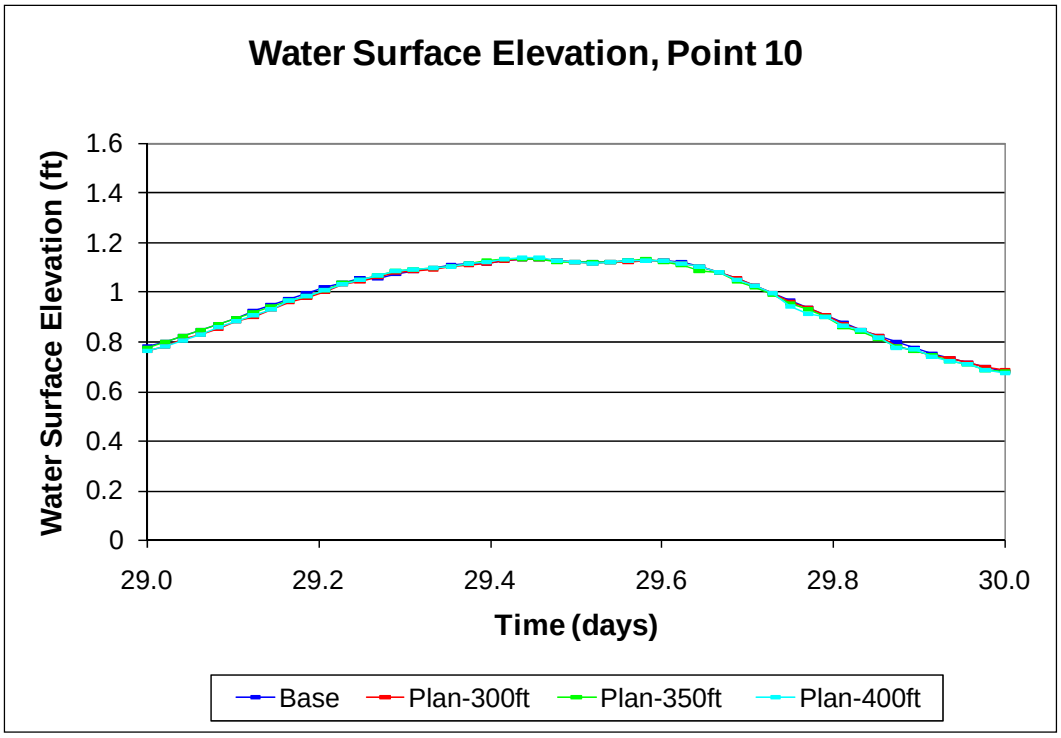

Figure 205. Water surface comparison for day 29 at point 10 for 300/350/400 plan set.

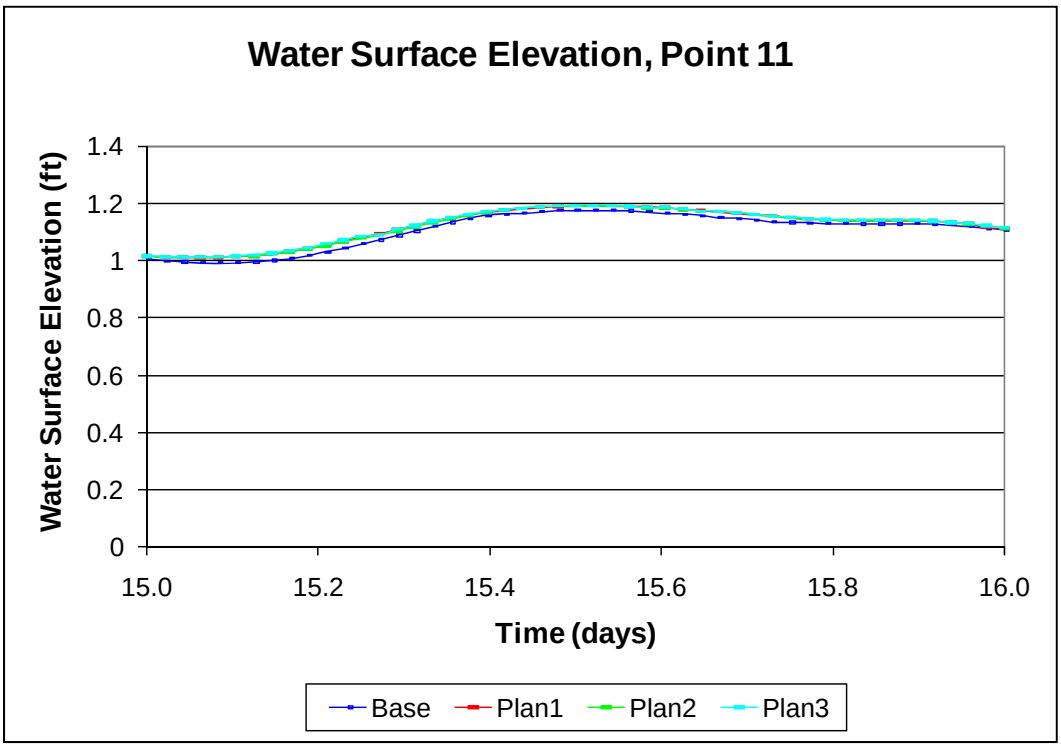

Figure 206. Water surface comparison for day 15 at point 11 for Initial plan set.

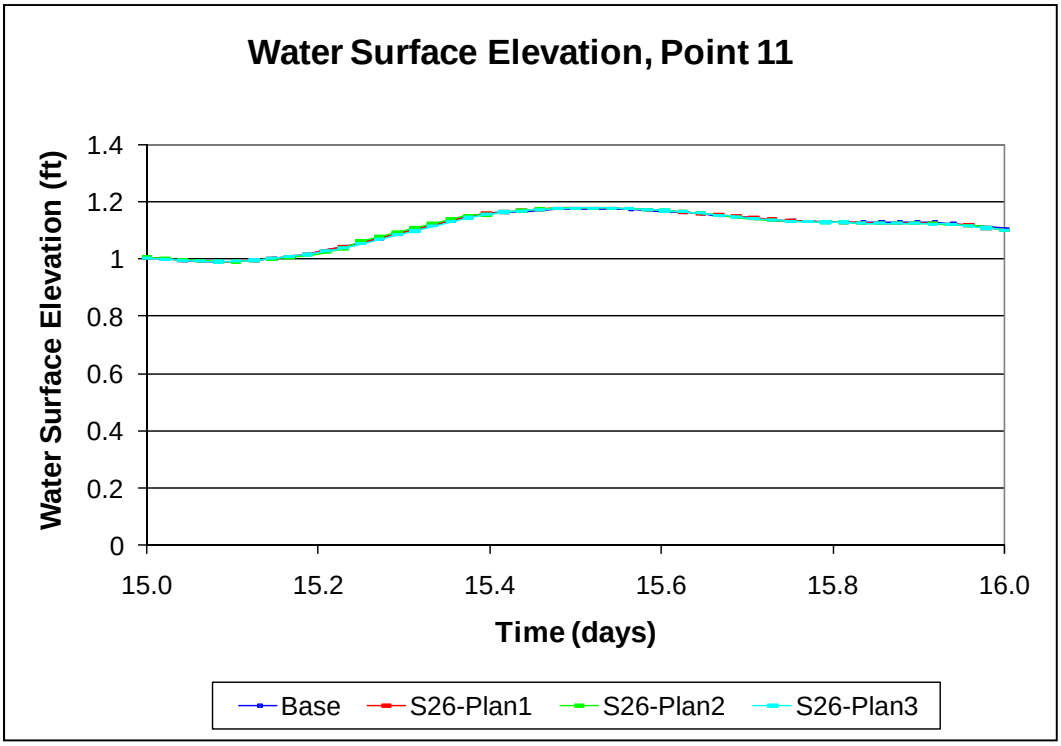

Figure 207. Water surface comparison for day 15 at point 11 for Station 26 plan set.

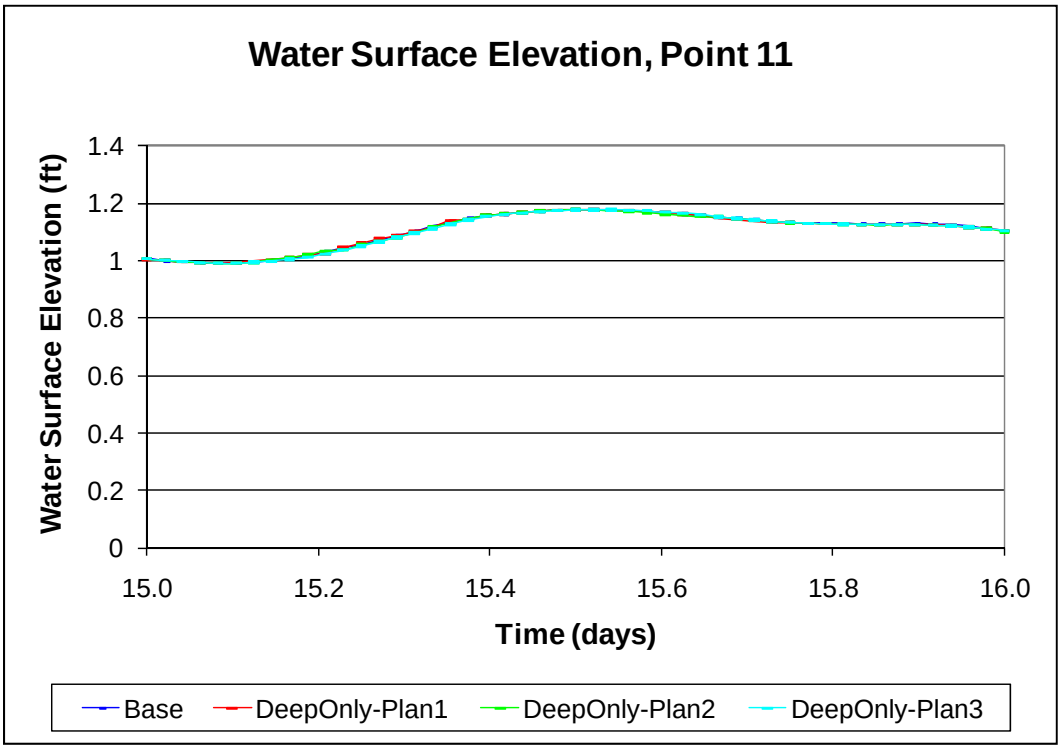

Figure 208. Water surface comparison for day 15 at point 11 for Deepen Only plan set.

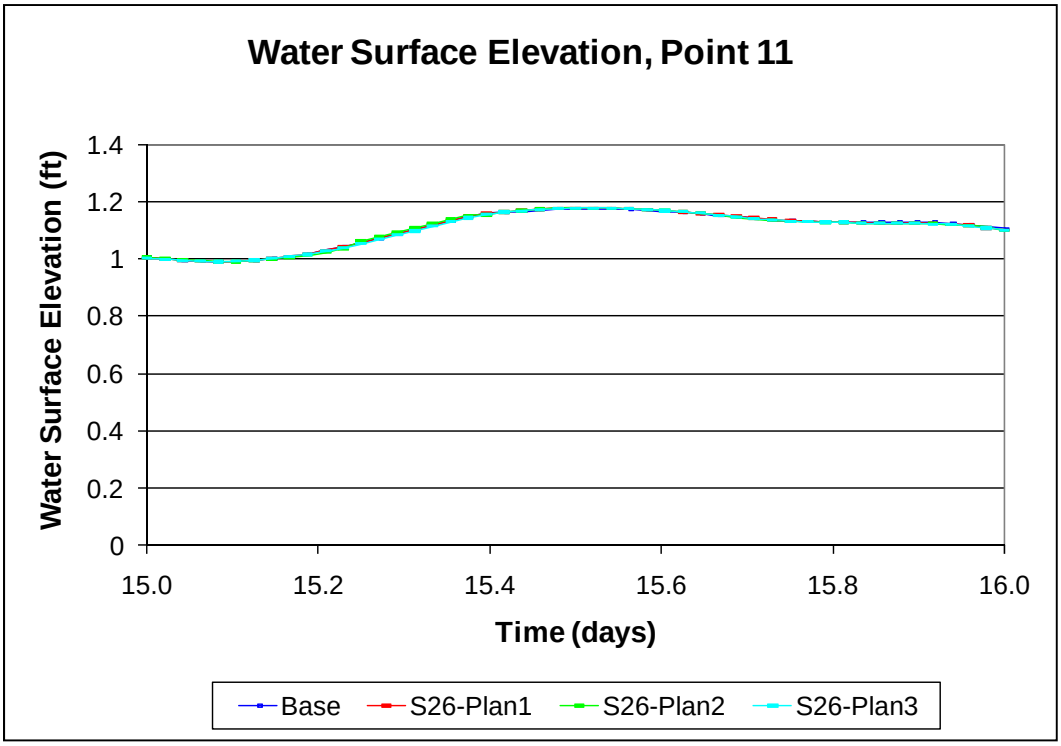

Figure 209. Water surface comparison for day 15 at point 11 for 300/350/400 plan set.

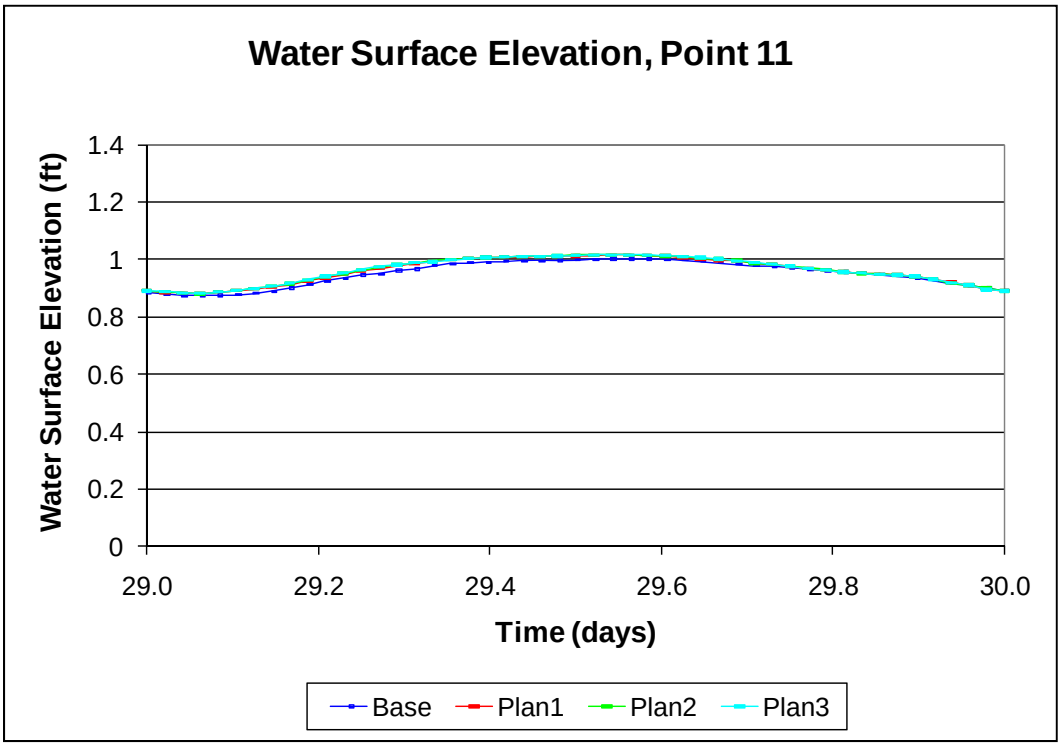

Figure 210. Water surface comparison for day 29 at point 11 for Initial plan set.

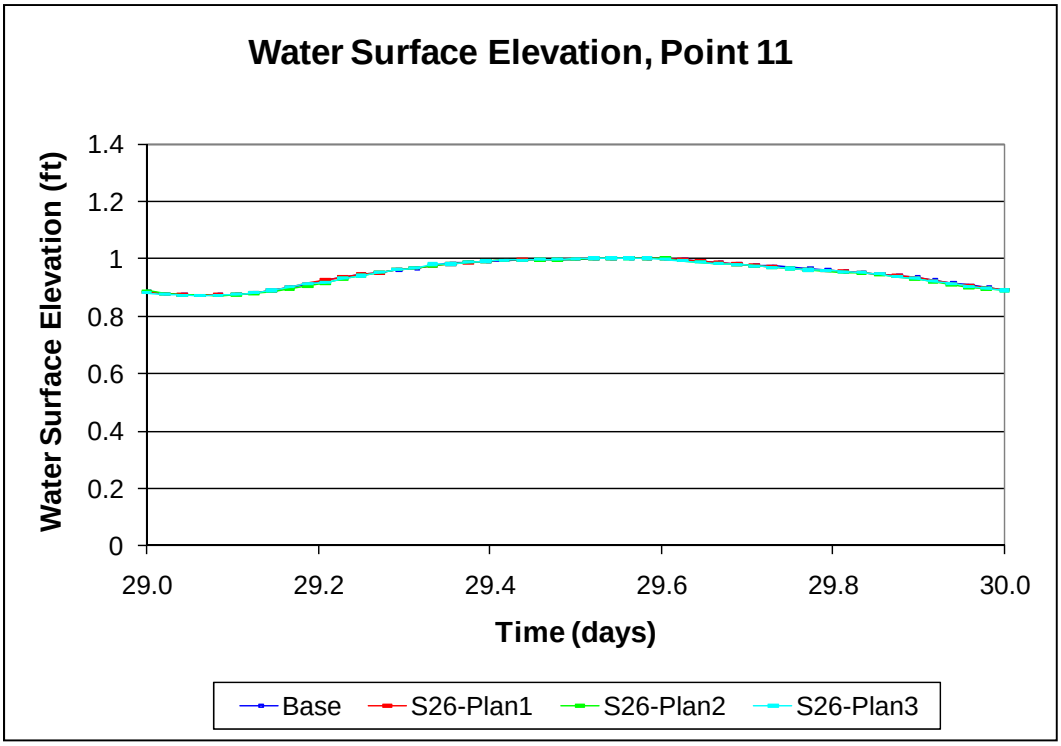

Figure 211. Water surface comparison for day 29 at point 11 for Station 26 plan set.

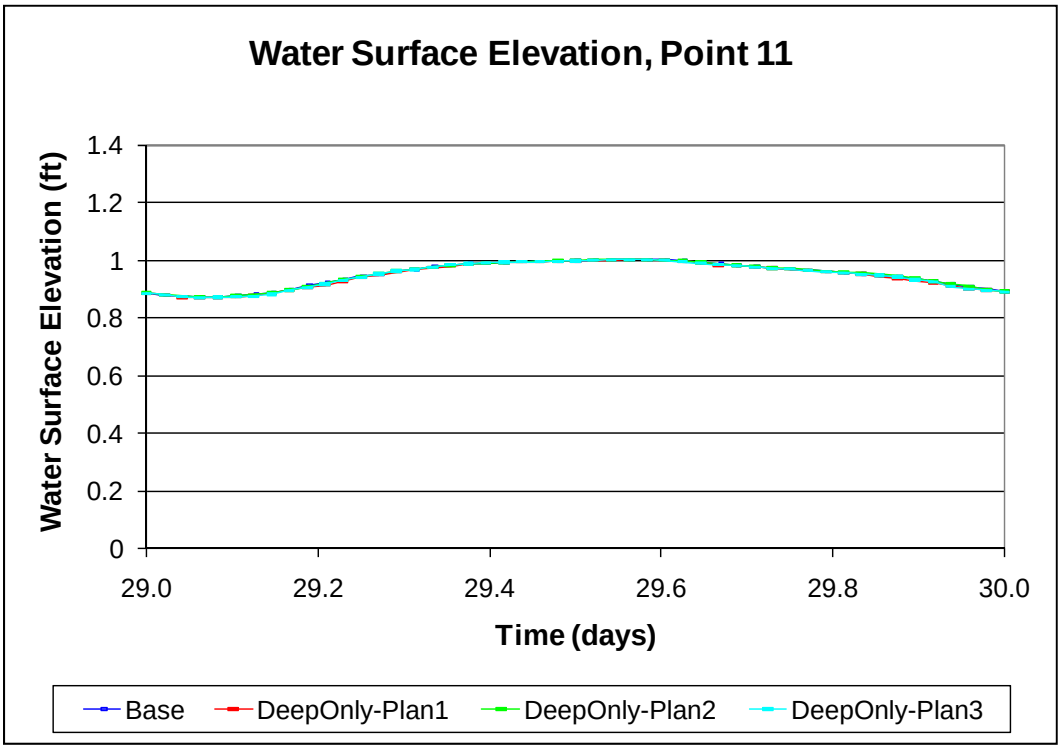

Figure 212. Water surface comparison for day 29 at point 11 for Deepen Only plan set.

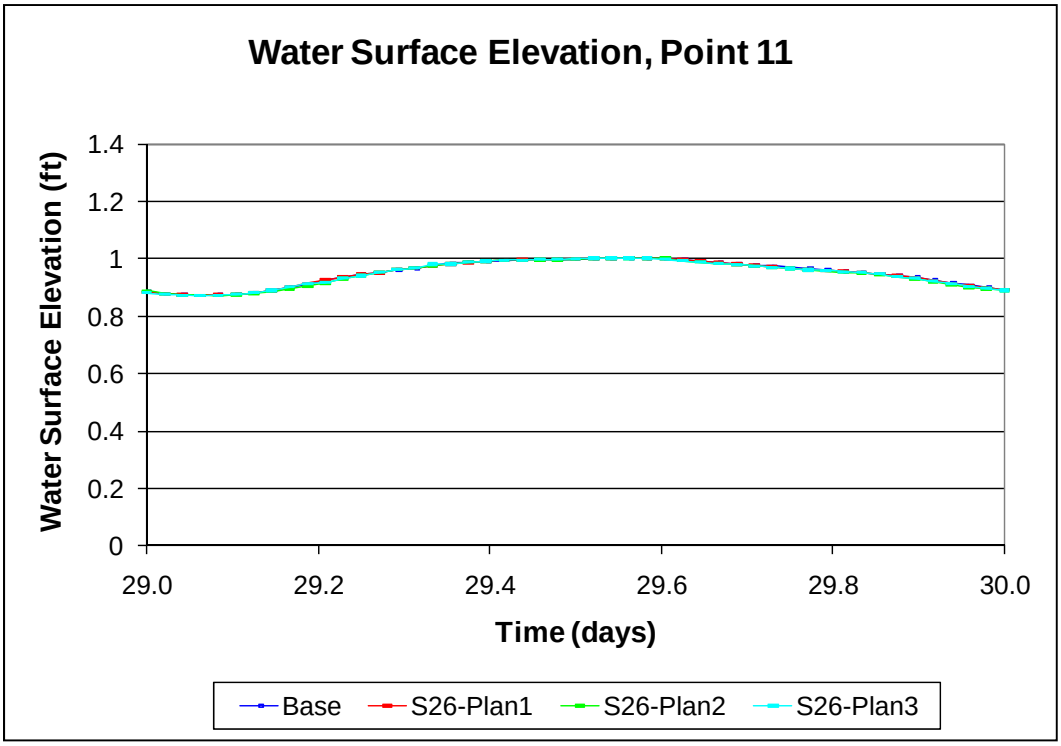

Figure 213. Water surface comparison for day 29 at point 11 for 300/350/400 plan set.

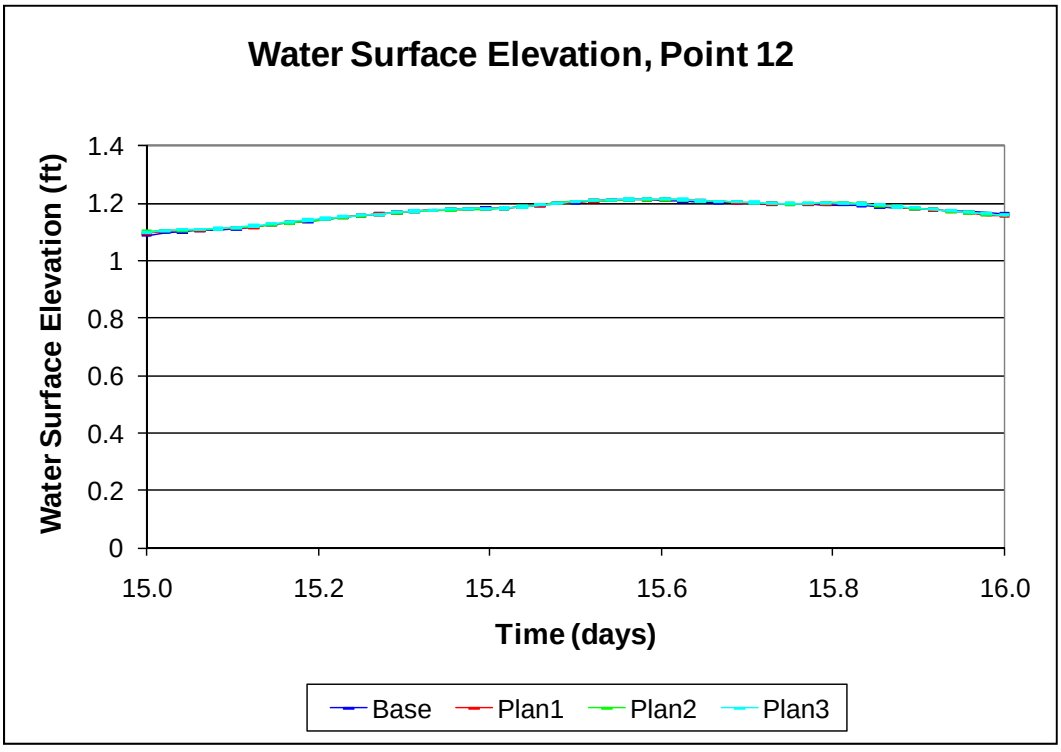

Figure 214. Water surface comparison for day 15 at point 12 for Initial plan set.

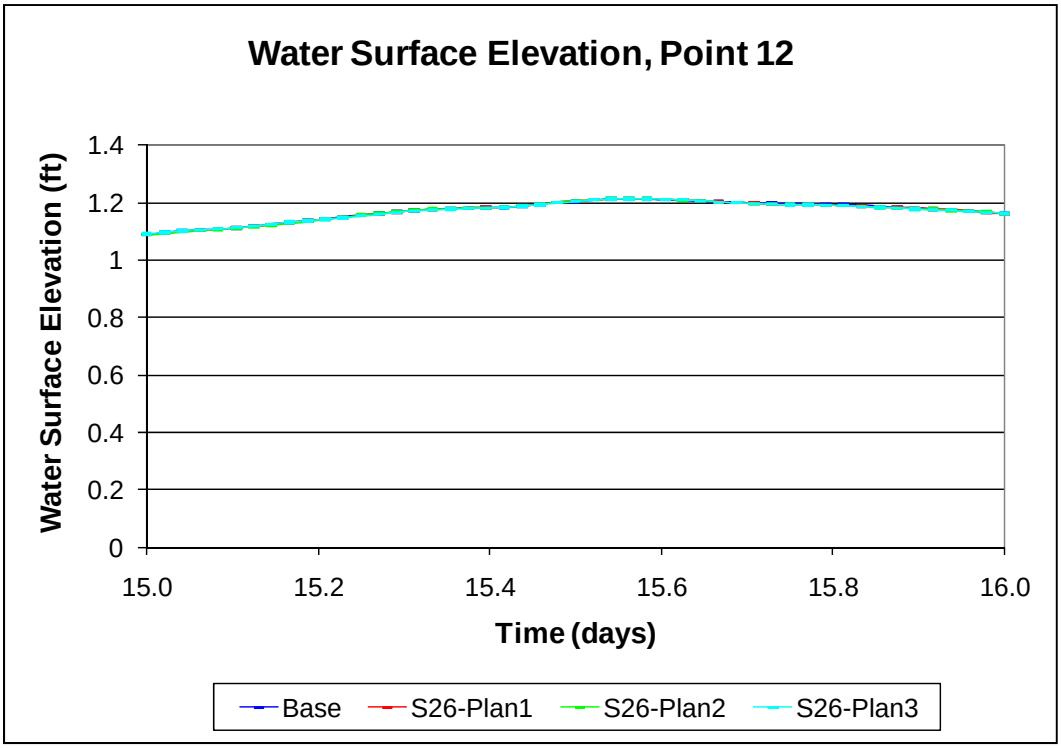

Figure 215. Water surface comparison for day 15 at point 12 for Station 26 plan set.

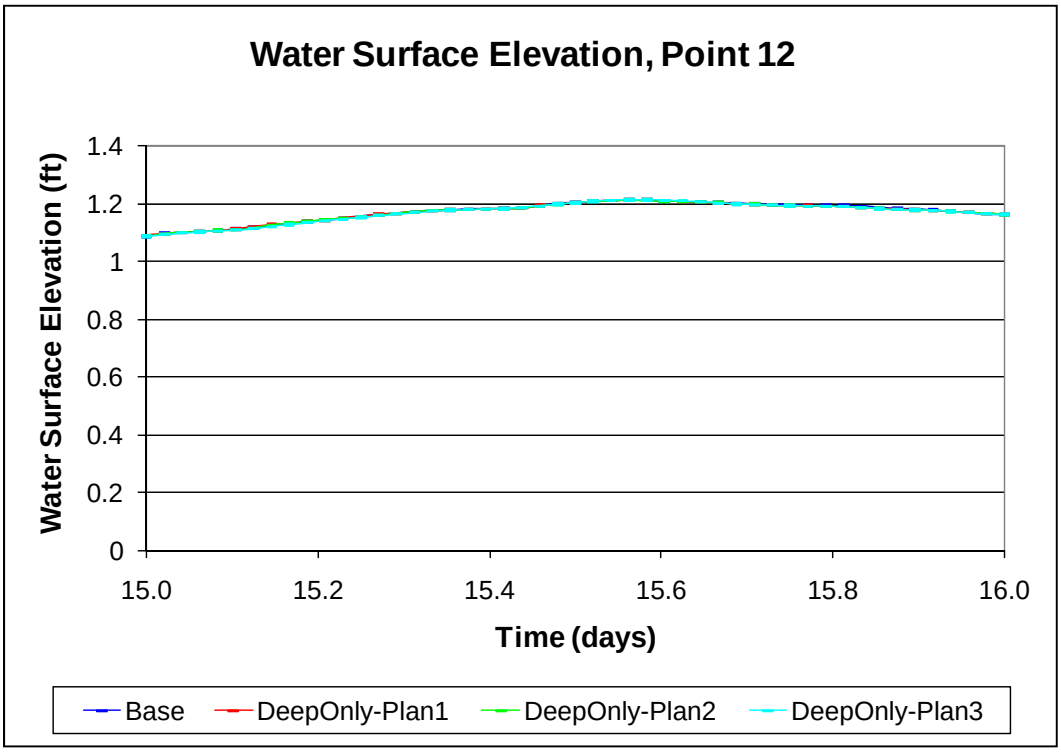

Figure 216. Water surface comparison for day 15 at point 12 for Deepen Only plan set.

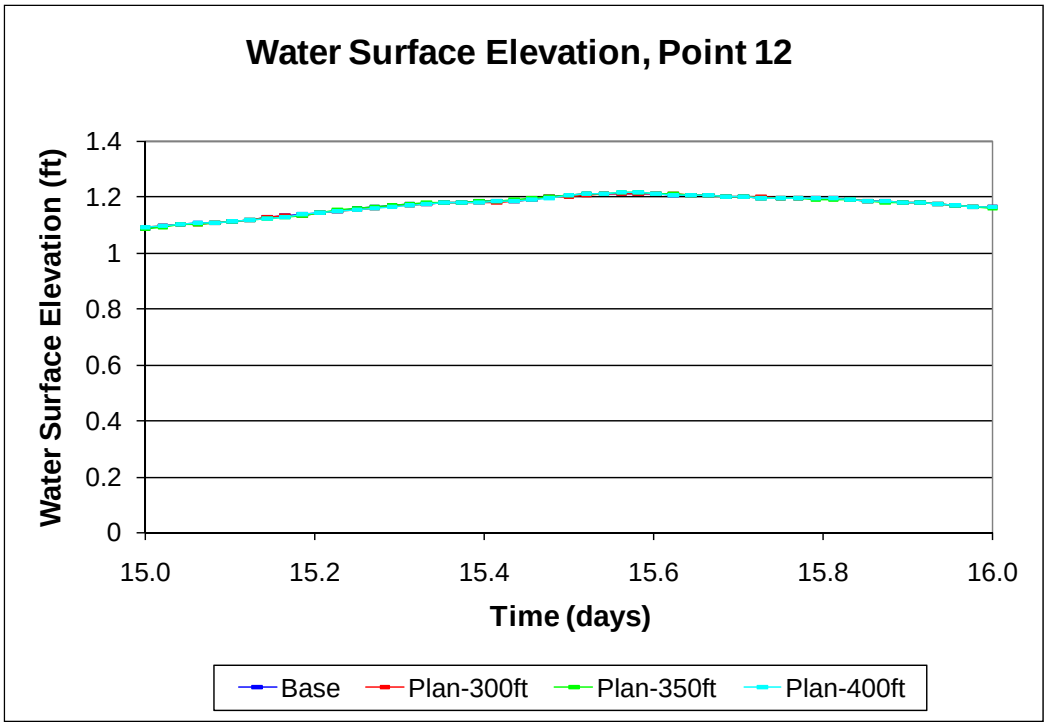

Figure 217. Water surface comparison for day 15 at point 12 for 300/350/400 plan set.

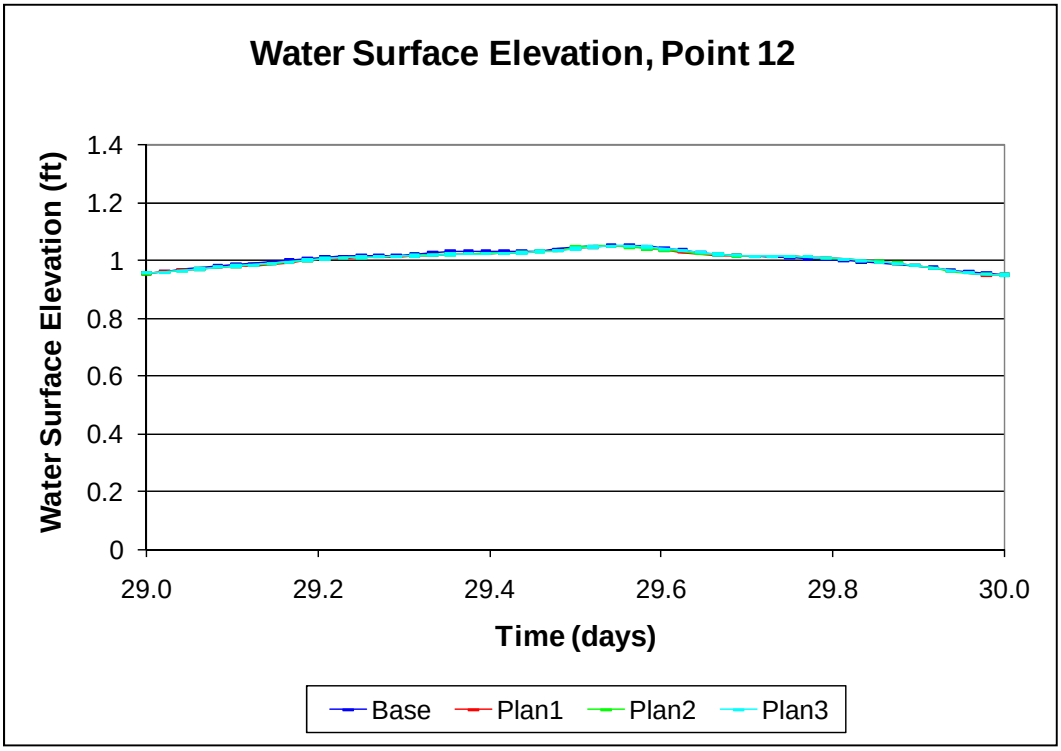

Figure 218. Water surface comparison for day 29 at point 12 for Initial plan set.

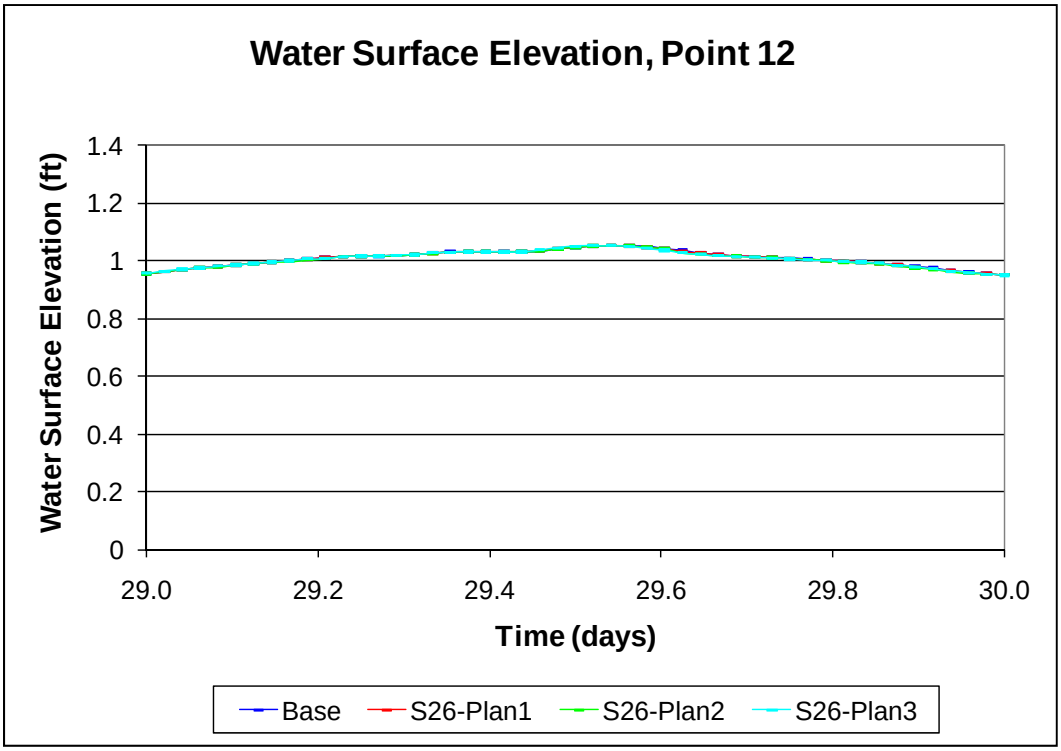

Figure 219. Water surface comparison for day 29 at point 12 for Station 26 plan set.

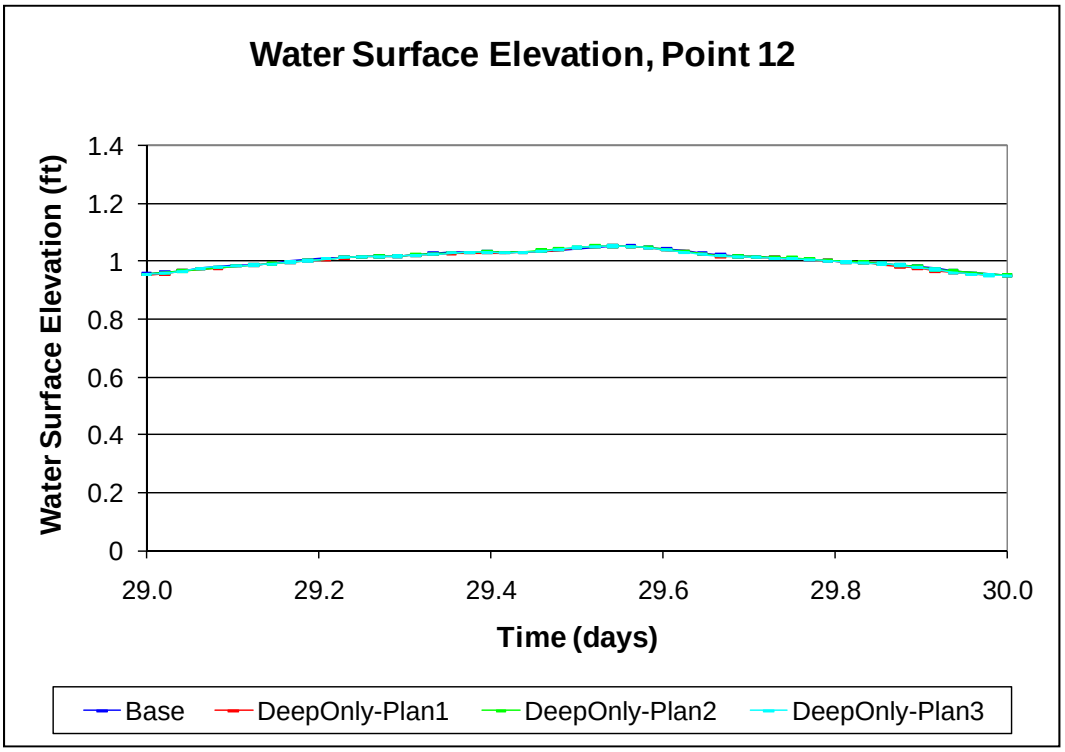

Figure 220. Water surface comparison for day 29 at point 12 for Deepen Only plan set.

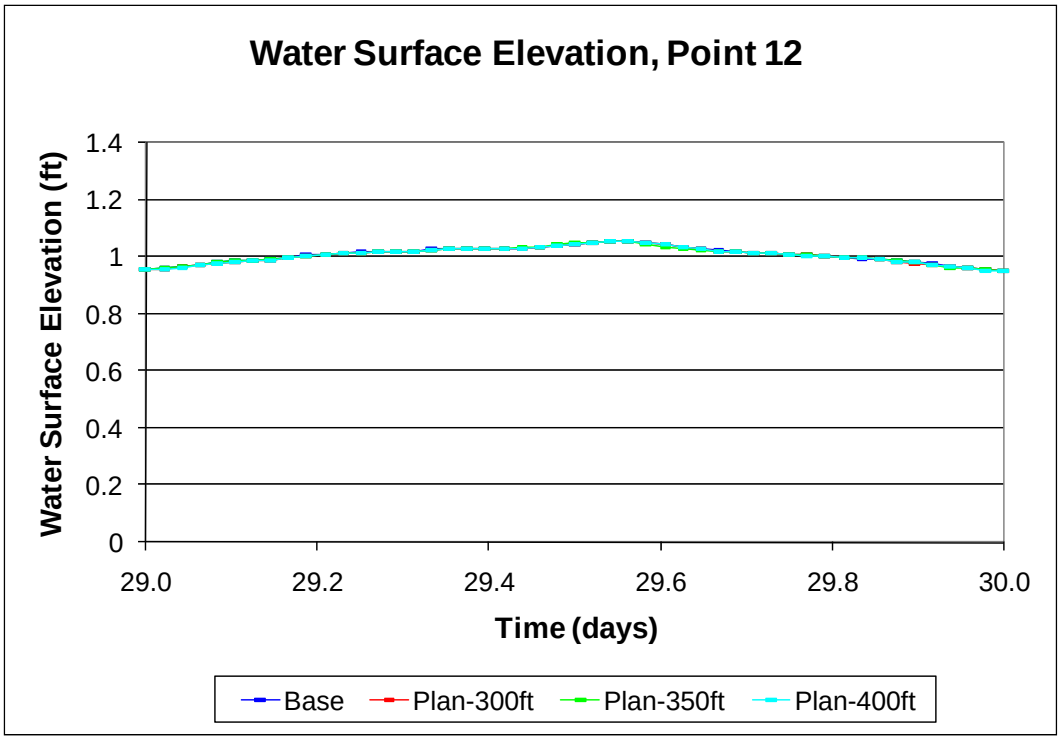

Figure 221. Water surface comparison for day 29 at point 12 for 300/350/400 plan set.

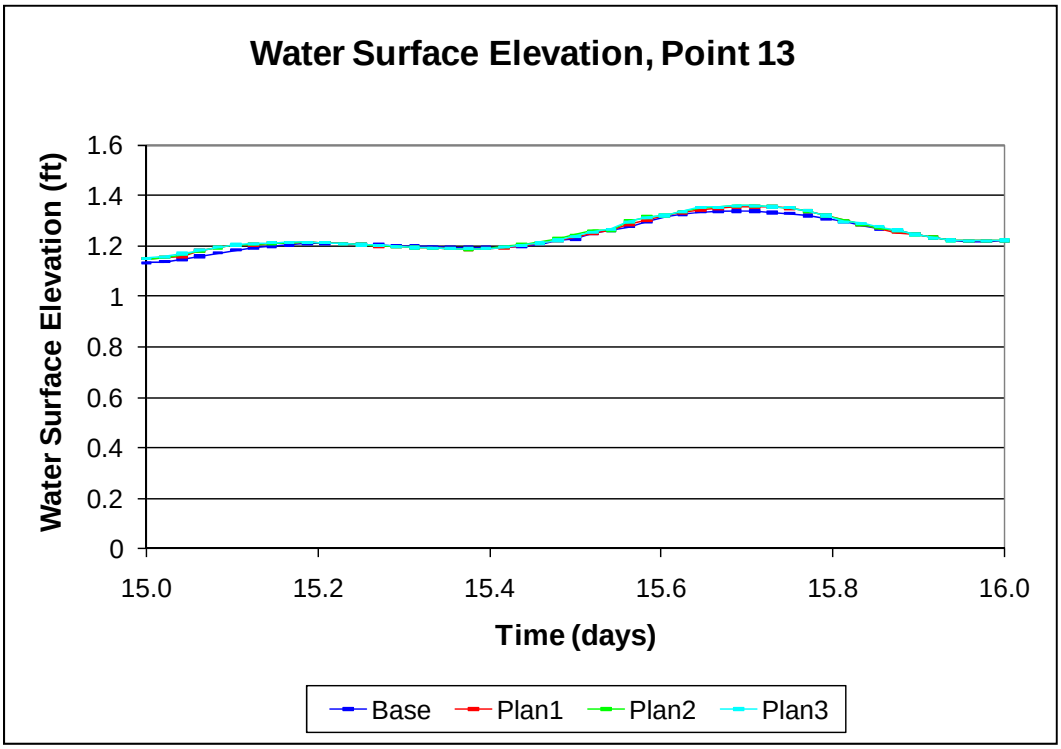

Figure 222. Water surface comparison for day 15 at point 13 for Initial plan set.

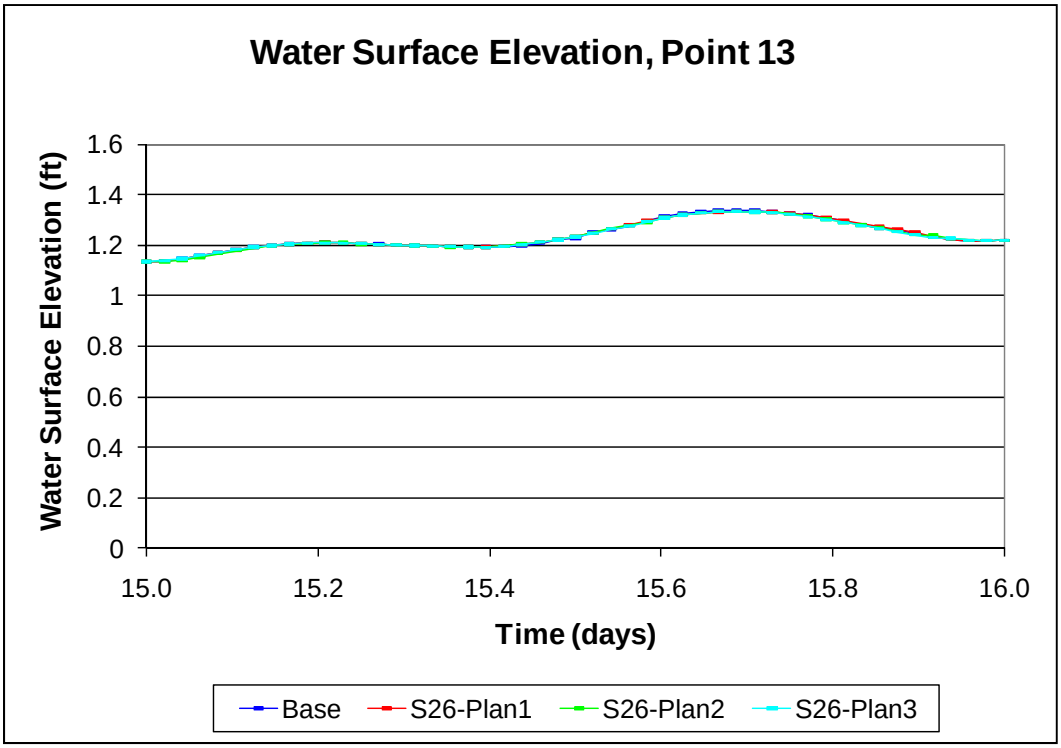

Figure 223. Water surface comparison for day 15 at point 13 for Station 26 plan set.

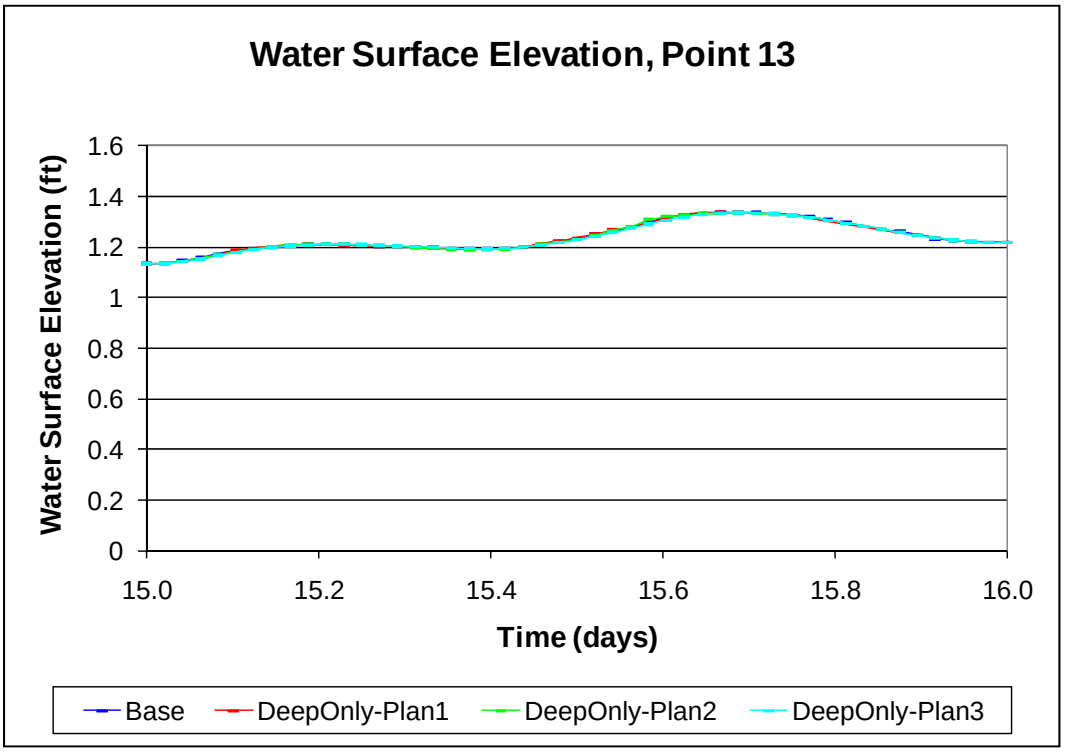

Figure 224. Water surface comparison for day 15 at point 13 for Deepen Only plan set.

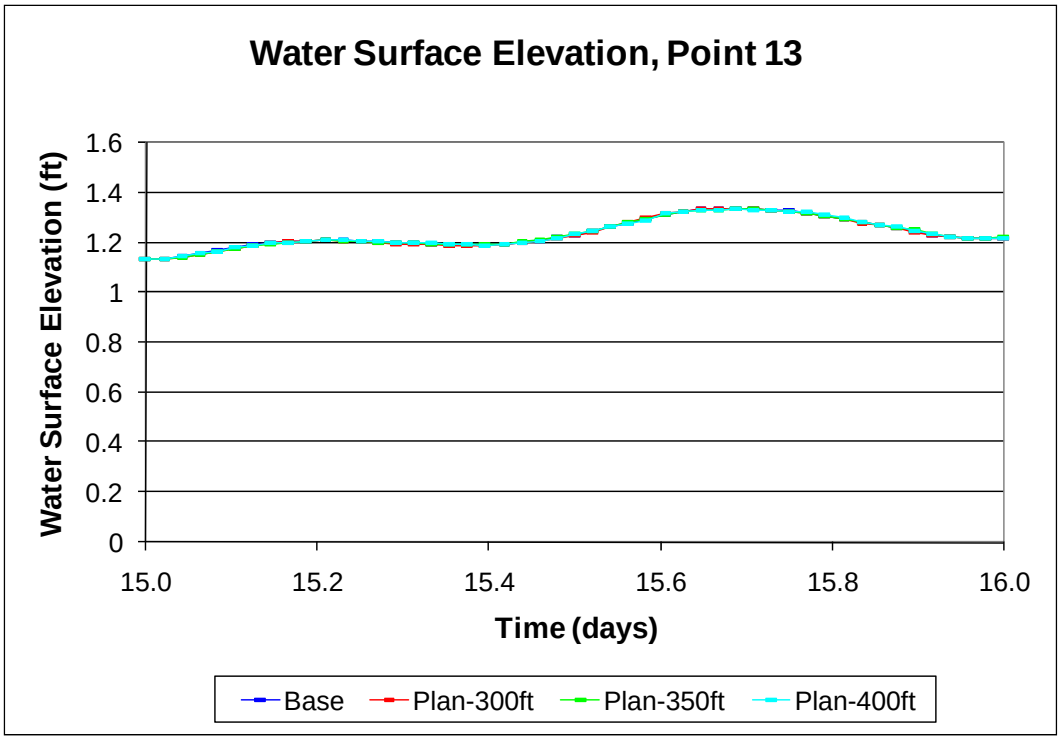

Figure 225. Water surface comparison for day 15 at point 13 for 300/350/400 plan set.

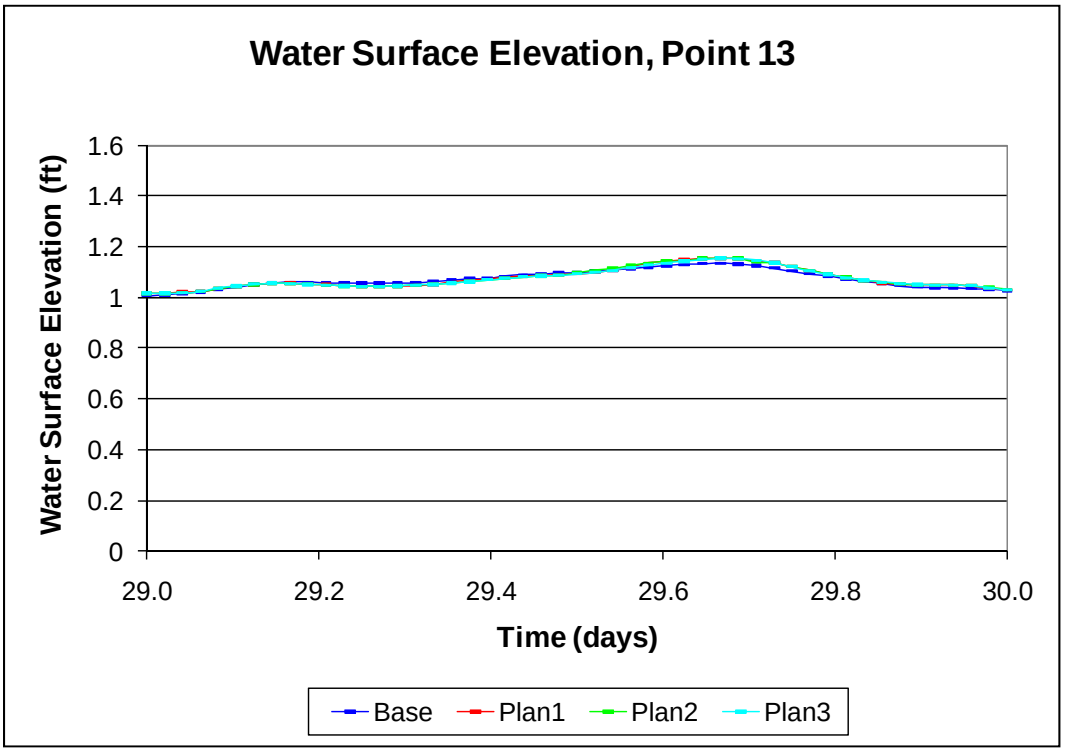

Figure 226. Water surface comparison for day 29 at point 13 for Initial plan set.

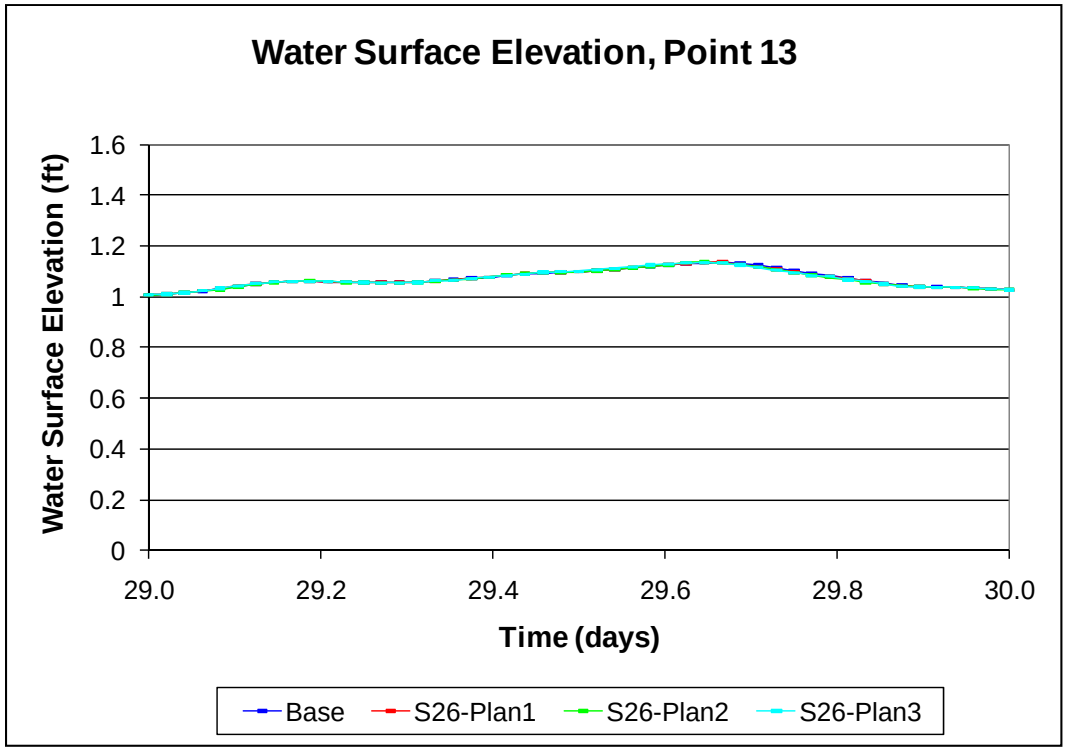

Figure 227. Water surface comparison for day 29 at point 13 for Station 26 plan set.

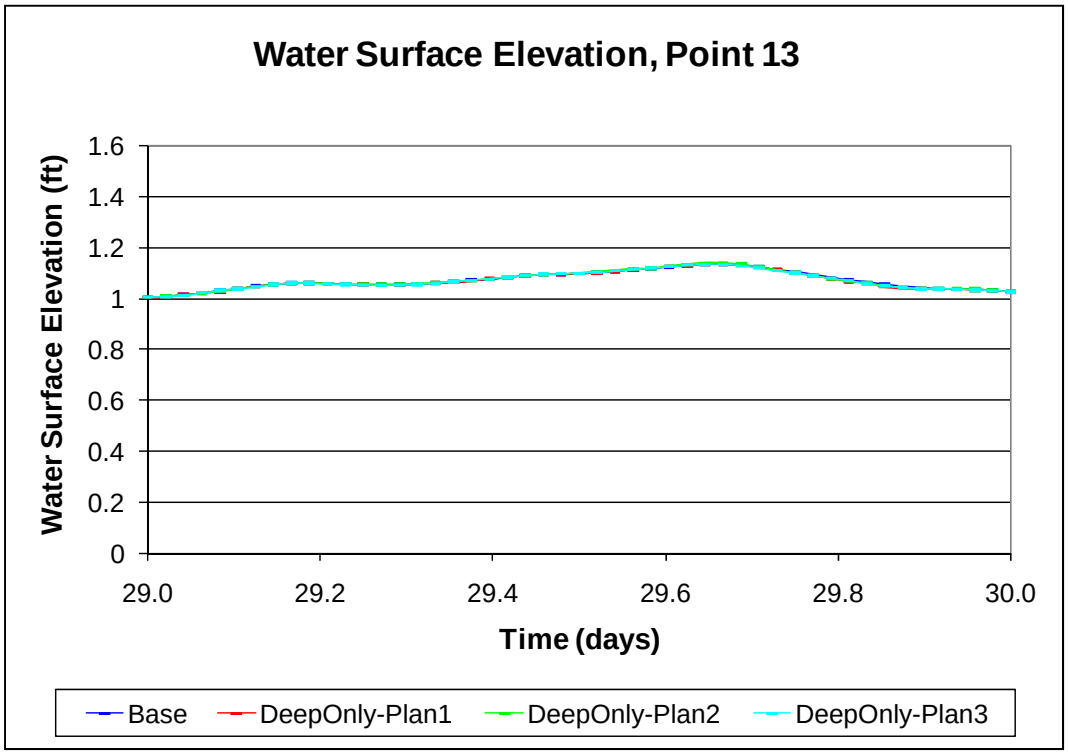

Figure 228. Water surface comparison for day 29 at point 13 for Deepen Only plan set.

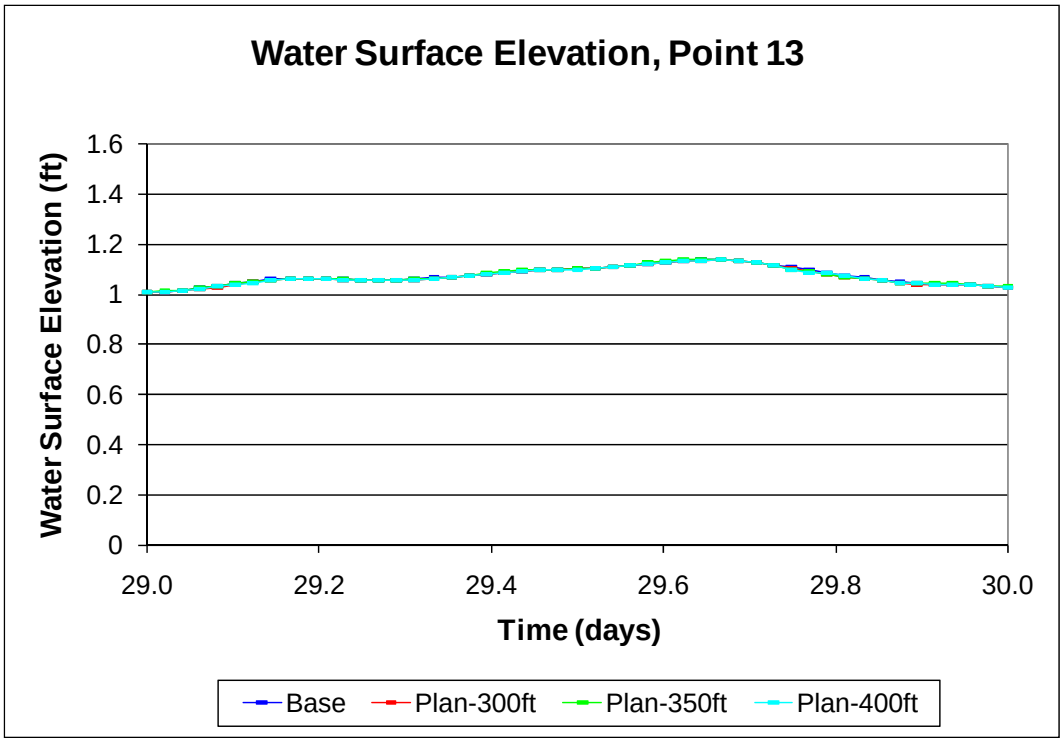

Figure 229. Water surface comparison for day 29 at point 13 for 300/350/400 plan set.

An additional water surface elevation analysis location at South Bay was requested by SWG. This location is shown in Figure 230 and is located south of the navigation channel in the center of the entrance to South Bay. Figures 231 – 238 show the water surface elevations for day 15 and 29 for each simulation set: deepening and widening; deepening and widening to Station 26; deepening only; and the 300/350/400 plan set.

The water surface elevation at this location is very similar to that at locations 2 and 3. There is some variation among plans at the low end of the tidal cycle, but this change is very small at the South Bay location. Overall, it appears that the changes to the navigation channel generate effects on the water levels in the South Bay area similar to those in the channel.

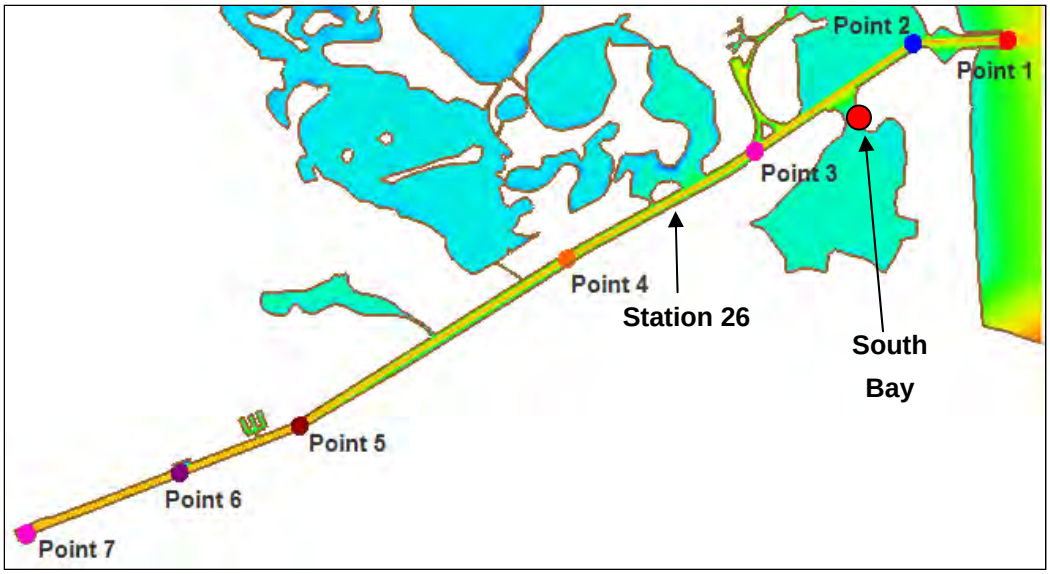

Figure 230. South Bay water surface elevation analysis location.

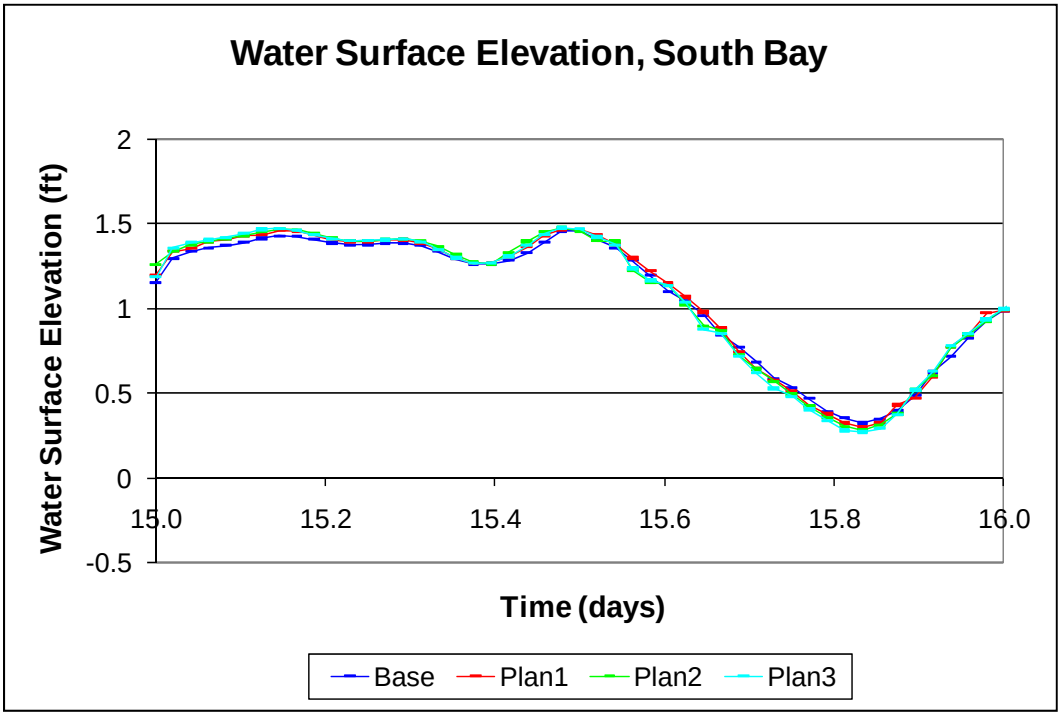

Figure 231. Water surface comparison for day 15 at South Bay for Initial plan set.

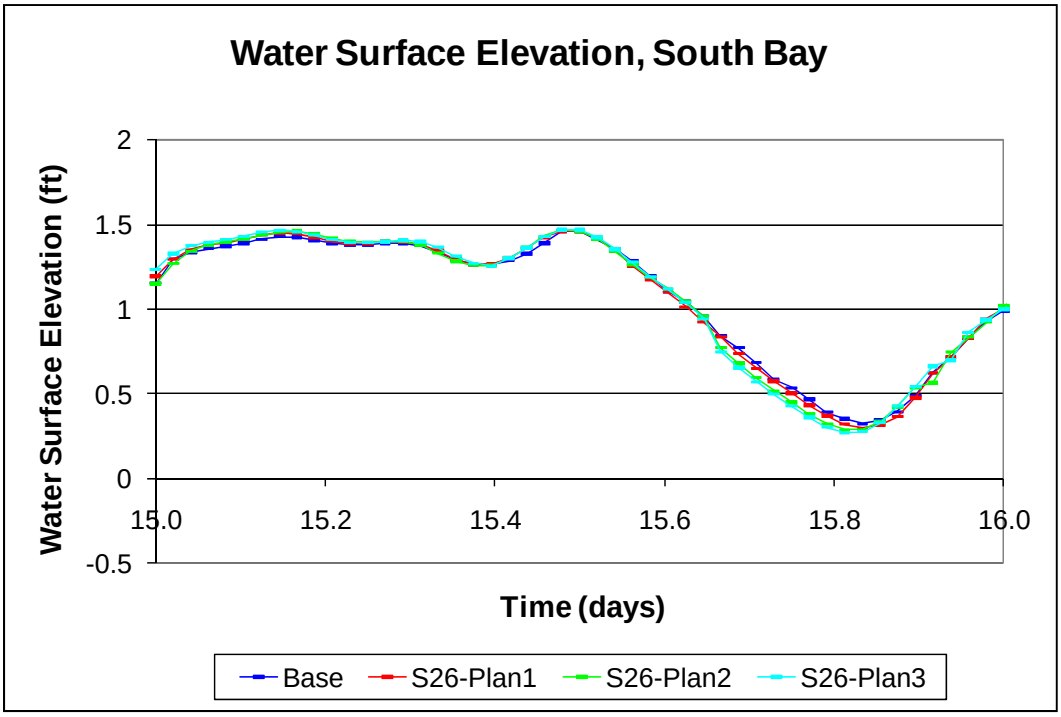

Figure 232. Water surface comparison for day 15 at South Bay for Station 26 plan set.

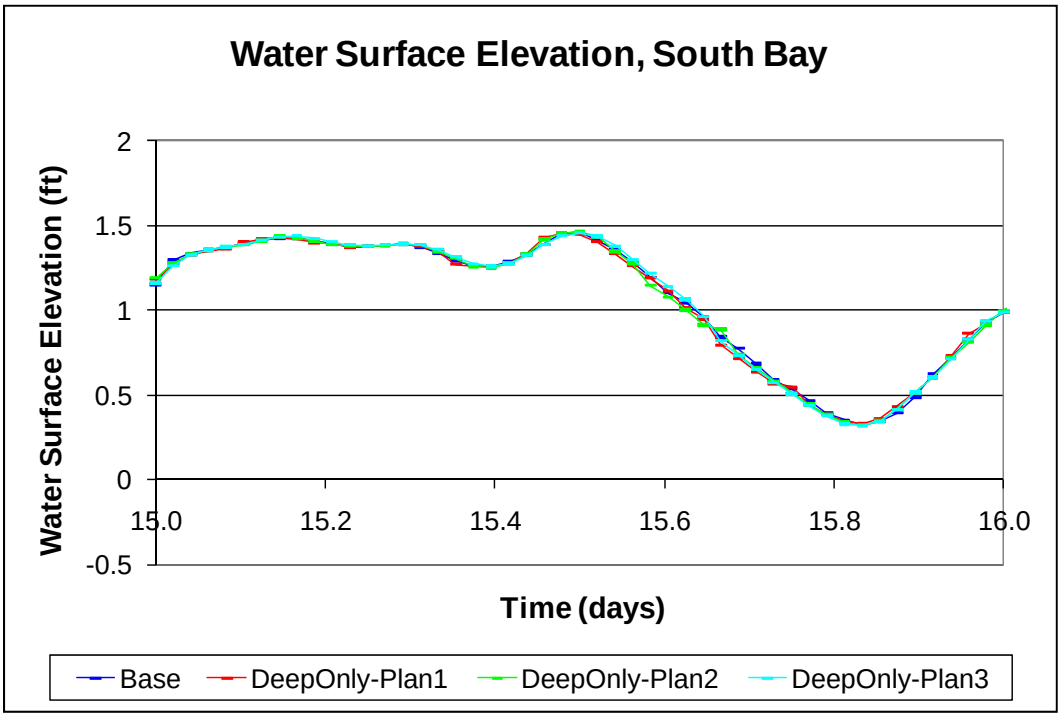

Figure 233. Water surface comparison for day 15 at South Bay for Deepen Only plan set.

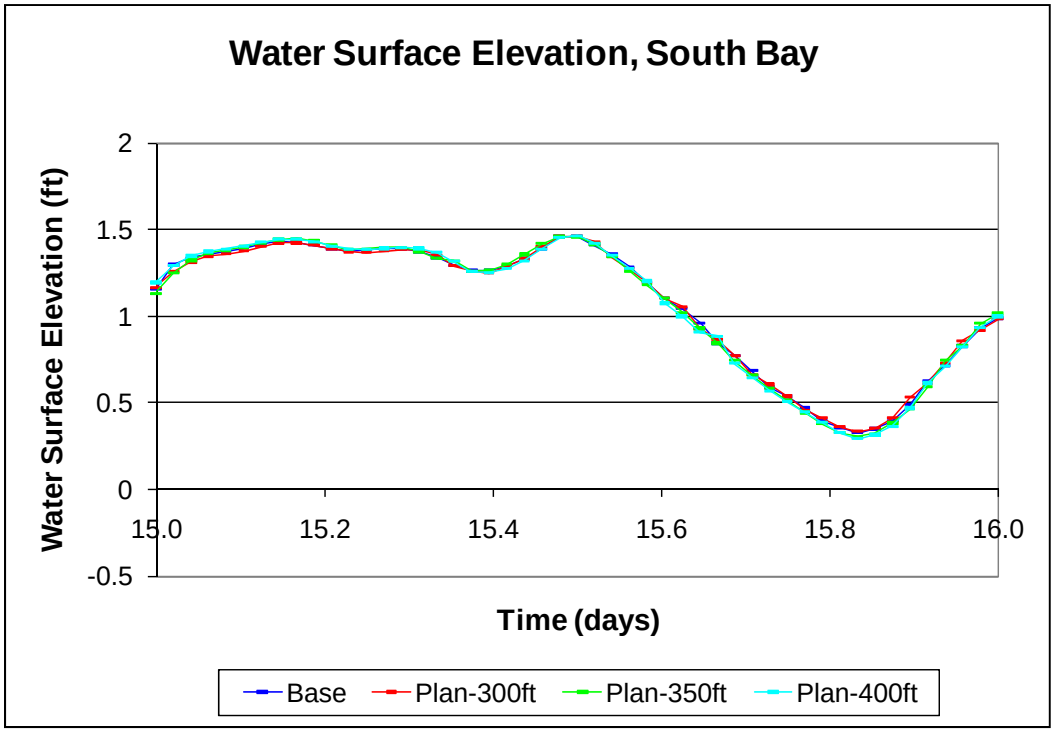

Figure 234. Water surface comparison for day 15 at South Bay for 300/350/400 plan set.

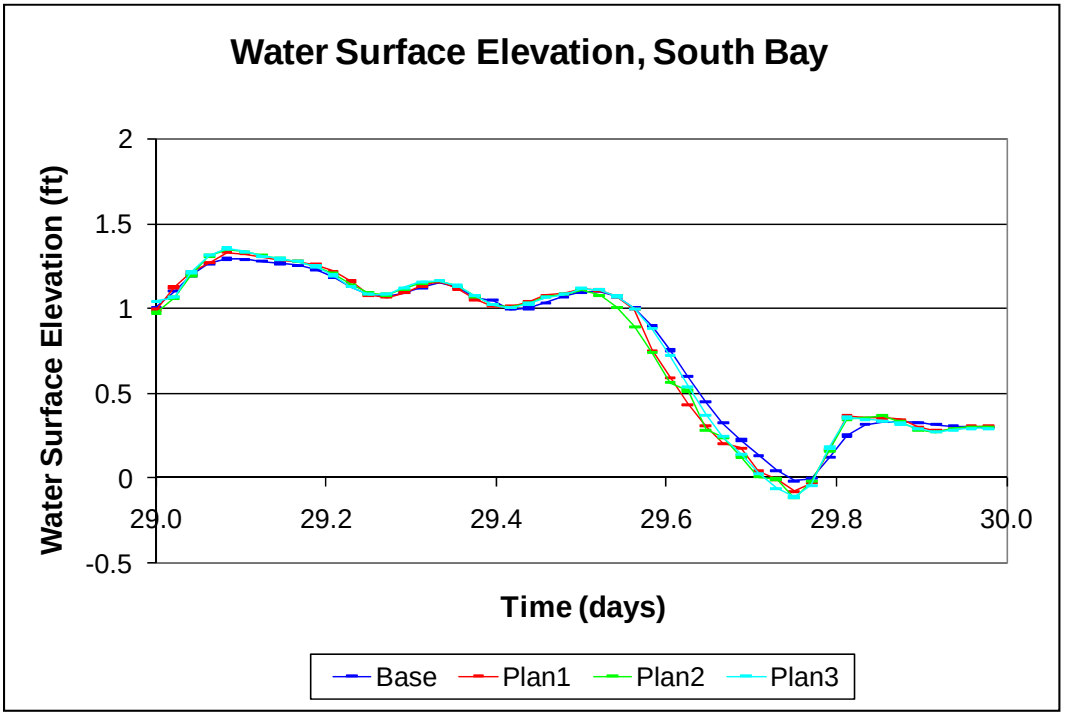

Figure 235. Water surface comparison for day 29 at South Bay for Initial plan set.

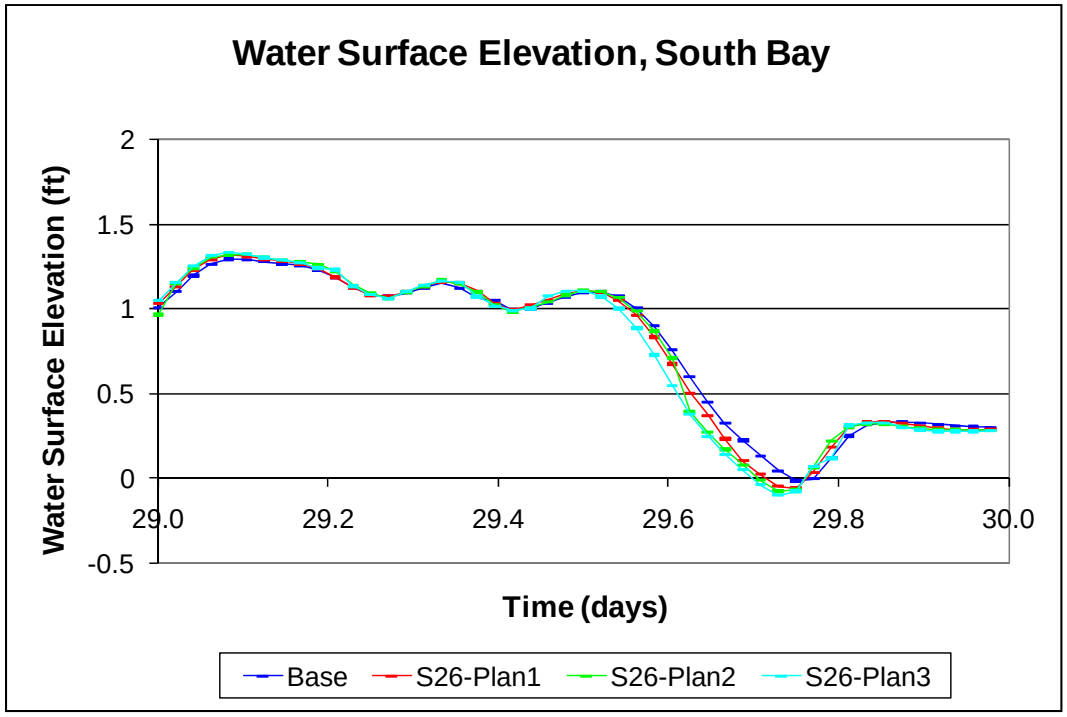

Figure 236. Water surface comparison for day 29 at South Bay for Station 26 plan set.

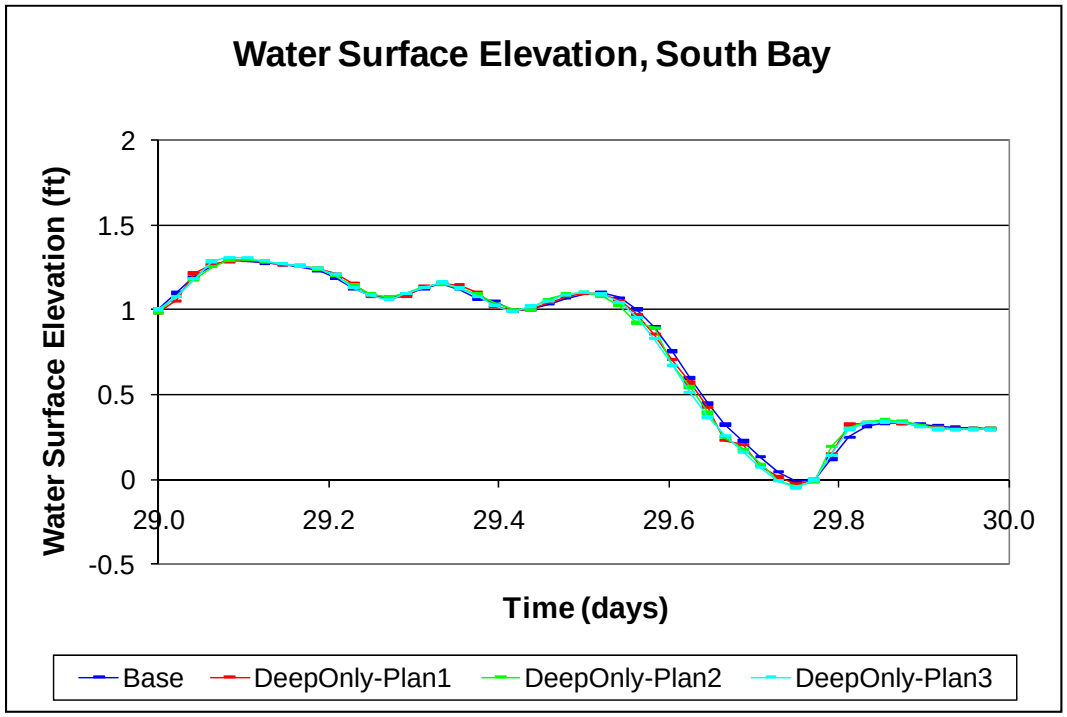

Figure 237. Water surface comparison for day 29 at South Bay for Deepen Only plan set.

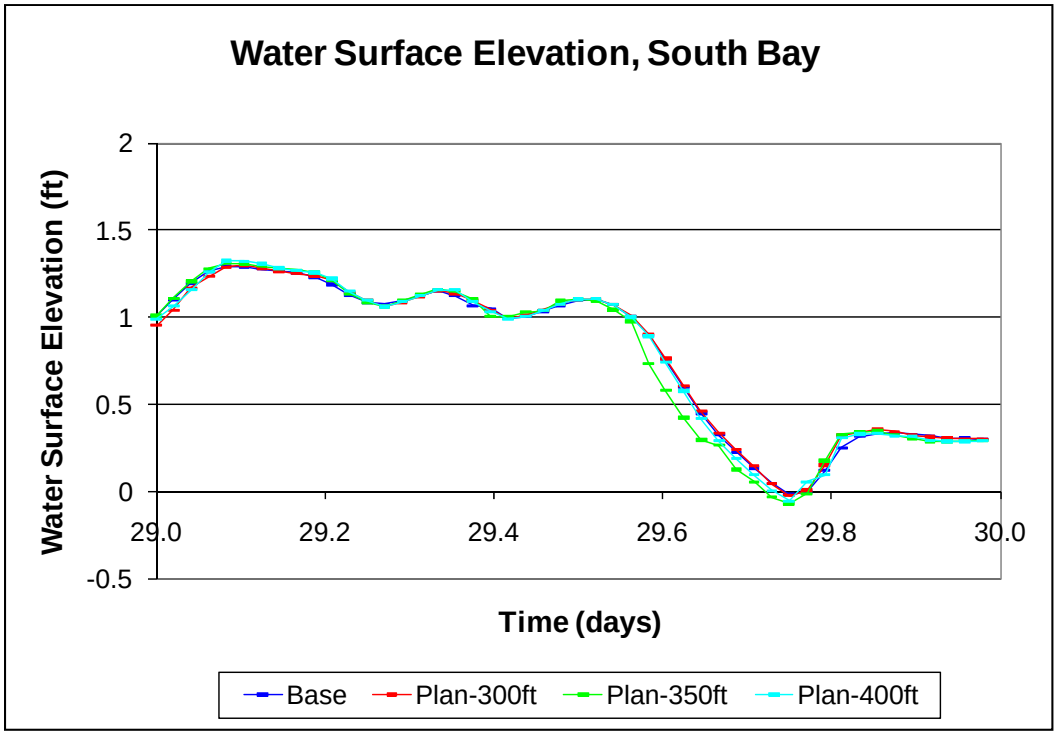

Figure 238. Water surface comparison for day 29 at South Bay for 300/350/400 plan set.

5 Conclusions

This report documents the development of a two-dimensional numerical model for the Brownsville Ship Channel including the lower Laguna Madre. Model validation was initially set up to replicate a previous model study of the area performed at ERDC-CHL[12], and the model was validated to 1997 data. The model replicated the field data well in the southern area of the domain and the ship channel. The lower Laguna Madre area was not replicated as accurately for water surface elevation, but the model/field data comparisons are sufficient for comparisons of the Base condition and simulations of alternate plans.

The validated model was used to analyze changes to the discharge, velocity, and water surface elevation for several plan conditions that include widening and deepening the entire ship channel or sections thereof. These comparisons show that a change in width greatly affects the velocity variation across the ship channel while the change to overall discharge is small. The velocities in the channel are quite low at a distance from the entrance to the Gulf of Mexico. The water surface elevations also remain unchanged, essentially, from the Base condition at all locations including South Bay. These low velocities and the fact that the plan changes do not greatly change the magnitudes of velocity and water surface elevation from the Base condition indicate that none of these changes to the ship channel should adversely impact navigation along the channel. However, results from these model studies are provided for a ship simulation study whereby further navigational analyses can be performed.

[12] Teeter et al., *Wind-Wave Resuspension*, January 2003.

Appendix: Description of the Adaptive Hydraulics Model (AdH)

Adaptive Hydraulics (AdH) is a state-of-the-art modeling system developed by the US Army Corps of Engineers Research and Development Center Coastal and Hydraulics Laboratory. It is capable of simulating both saturated and unsaturated groundwater flow, overland flow, three-dimensional Navier-Stokes flow, and two- or three-dimensional shallow-water problems. The current study utilizes the two-dimensional (2D) shallow-water module. The 2D shallow-water equations used for this application are a result of the vertical integration of the equations of mass and momentum conservation for incompressible flow under the hydrostatic pressure assumption. Written in conservative form, the 2D shallow-water equations are:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} + \mathbf{H} = 0 \tag{1}$$

where

$$\mathbf{U} = \begin{Bmatrix} h \\ uh \\ vh \end{Bmatrix} \tag{2}$$

$$\mathbf{F} = \begin{Bmatrix} uh \\ u^2 h + \frac{1}{2} g h^2 - h\frac{\sigma_{xx}}{\rho} \\ uvh - h\frac{\sigma_{yx}}{\rho} \end{Bmatrix} \tag{3}$$

$$\mathbf{G} = \begin{Bmatrix} vh \\ uvh - h\frac{\sigma_{xy}}{\rho} \\ v^2 h + \frac{1}{2} g h^2 - h\frac{\sigma_{yy}}{\rho} \end{Bmatrix} \tag{4}$$

and

$$\mathbf{H} = \begin{Bmatrix} 0 \\ gh\dfrac{\partial z_b}{\partial x} + n^2 gh\dfrac{u\sqrt{u^2+v^2}}{C_o h^{1/3}} \\ gh\dfrac{\partial z_b}{\partial y} + n^2 gh\dfrac{v\sqrt{u^2+v^2}}{C_o h^{1/3}} \end{Bmatrix} \tag{5}$$

where:

ρ = fluid density
g = gravitational acceleration
z_b = bottom elevation
n = Manning's roughness coefficient
h = flow depth
u = x-component of velocity
v = y-component of velocity
C_o = dimensional conversion coefficient (1 for SI units, 1.486 for US customary units)
σ_{ij} = the Reynolds stresses due to turbulence, where the first subscript (i) indicates the direction, and the second (j)indicates the face on which the stress acts.

The Reynolds stresses are determined using the Boussinesq approach to the gradient in the mean currents.

$$\sigma_{xx} = 2\rho\nu_t \frac{\partial u}{\partial x} \tag{6}$$

$$\sigma_{yy} = 2\rho\nu_t \frac{\partial v}{\partial y} \tag{7}$$

and

$$\sigma_{xy} = \sigma_{yx} = 2\rho\nu_t \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \tag{8}$$

where ν_t = kinematic eddy viscosity (which varies spatially).

The AdH shallow-water equations are placed in conservative form so that mass balance and the balance of momentum and pressure are identical across an interface. This is important in order to match the speed and height of a surge or hydraulic jump.

The equations are represented using a finite element approach. The quality of the numerical solution depends on the choice of the basis/trial function and the test function. The trial function determines how the variables are represented and the test function determines the manner in which the differential equation is enforced. In the Galerkin approach the test functions are chosen to be identical with the trial functions. When the flow is advection-dominated, the Galerkin approach produces oscillatory behavior. The Galerkin form of the test function cannot detect the presence of a node-to-node oscillation and so allows this spurious solution. The approach used in AdH is to enrich the standard Galerkin test function with an additional term that can detect and control this spurious solution.

The enriched Galerkin method used here, the Petrov-Galerkin method, is based on elemental constants for coefficients to stabilize these spurious oscillations. This reduces the stabilization to the nonconservative form. This is not a problem for mass or momentum conservation since the stabilization is only applied within the elements and uses the Galerkin test function to enforce “flux” balance across element edges.

For illustration of this technique, consider the shallow-water equations in nonconservative form

$$\frac{\partial U}{\partial t} + A\frac{\partial U}{\partial x} + B\frac{\partial U}{\partial y} + H = 0 \tag{9}$$

where $A = \frac{\partial F}{\partial U}$ and $B = \frac{\partial G}{\partial U}$. The trial functions (or interpolation/basis functions) are the Lagrange polynomials. These are piecewise linear functions that are continuous across element boundaries. Spatial derivatives, however, are not continuous across these element edges. Each of the dependent and independent variables is interpolated via these trial functions. For example,

$$\tilde{u}(x) = \sum_{j=1}^{N} \phi_j(x) u_j \tag{10}$$

,

means that the approximate solution is made up of the product of the trial function for node j, ϕ_j, and the nodal value at that location, u_j. The test function is chosen as:

$$\phi_i^* = \phi_i I + \alpha\left(\frac{\partial \phi_i}{\partial x} A + \frac{\partial \phi_i}{\partial y} B\right) \tag{11}$$

where,

$$\alpha = 0.5l\left[\bar{v} \bullet \bar{v} + gh + \left(\frac{l}{\Delta t}\right)^2\right]^{-1/2} \tag{12}$$

l = $(\Omega_e)^{1/2}$, the square of the element area
$\bar{v}$ = $(\bar{u}, \bar{v})$, the element average velocity components
Δt = time step size

The finite element statement becomes:

$$\int_\Omega \left(\phi_i \frac{\partial U_l}{\partial t} - \frac{\partial \phi_i}{\partial x} F_l - \frac{\partial \phi_i}{\partial y} G_l + \phi_i H_l\right) d\Omega + \int_{\partial\Omega} \phi_i \left\{F_l n_x + G_l n_y\right\} ds + \sum_e \int_{\Omega_e} \alpha\left(\frac{\partial \phi_i}{\partial x} A_l + \frac{\partial \phi_i}{\partial y} B_l\right)$$

$$\left(\frac{\partial U_l}{\partial t} + A_l \frac{\partial U_l}{\partial x} + B_l \frac{\partial U_l}{\partial y} + H_l\right) = 0 \tag{13}$$

where the subscript l indicates the finite element approximation. The Petrov-Galerkin contributions are integrated on the interior of the elements, but not across element edges. This contribution stabilizes the Galerkin approach. This scheme utilizes a single scaling factor α . This is different from the scheme reported in Berger and Stockstill[13]. That scheme involved scaling each eigenvalue, but that method does not converge using the iterative solver in AdH. Instead, a single value scaling (Equation 12) is used.

One of the major features of AdH is its ability to automatically adapt the mesh in areas where additional resolution is needed to properly resolve the hydrodynamics and then unresolve the area when the resolution is no

[13] Berger, R.C., and Stockstill, R.L. (1995). "Finite Element Model for High Velocity Channels," *Journal of Hydraulic Engineering*, 121(10), 710-716.

longer needed. This feature thus addresses the issue of computational burden while allowing adequate resolution for a good simulation. This adaptation process is done by normalizing the results so that an error quantity is determined for each element. If this error exceeds the tolerance set by the user, then the element is refined. AdH contains other essential features such as wetting and drying, completely coupled sediment transport, conservative transport (such as salinity), and wind effects. A series of modularized libraries make it possible for AdH to include vessel movement, friction descriptions, varying turbulence closures, and water quality and ecological modeling, among other features. AdH can run in parallel or on a single processor and runs on both Microsoft Windows and UNIX-based operating systems.

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14. ABSTRACT

The US Army Engineer District, Galveston, requested a numerical model of hydrodynamic changes that would result from each of several possible enlargements of the Brownsville Ship Channel in Brownsville, Texas. These plans include possible deepening and widening of the ship channel from its connection to the Gulf of Mexico to the turning basin approximately 18 miles inland. The model was validated to flow, wind, and tide conditions from June 1997. Model-specific parameters for bed roughness were set and used for the plan simulations. Velocity, discharge, and water surface analyses were performed at several locations along the ship channel to determine the impacts of the proposed changes.

15. SUBJECT TERMS
ADaptive Hydaulics (ADH), TABS-MDS, numerical modeling, channels (hydraulic engineering), Brownsville Ship Channel, ERDC Ship/Tow Simulator

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